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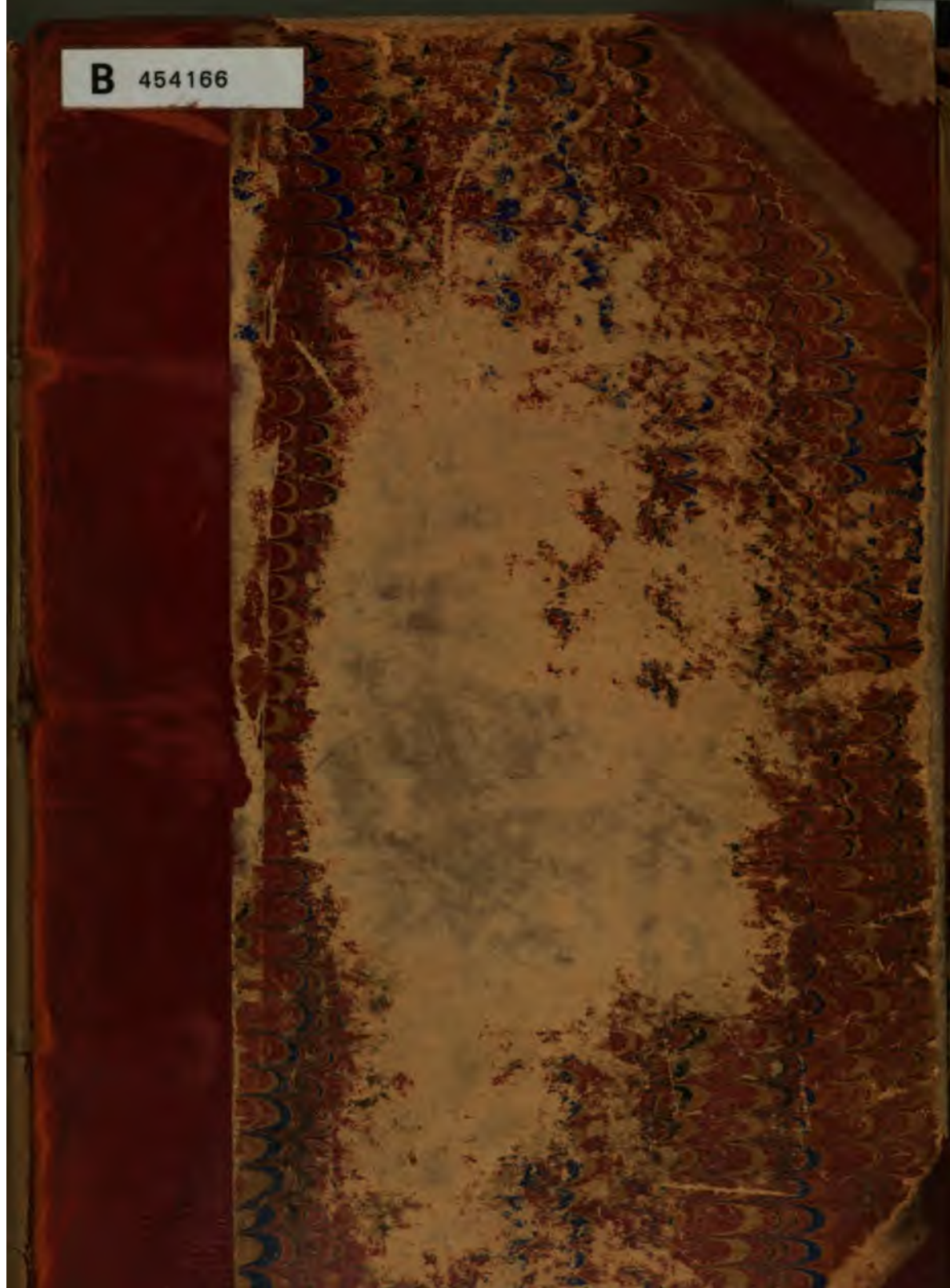
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METALLURGY.

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METALLURGY.

THE
ART OF EXTRACTING METALS FROM THEIR ORES.

BY JOHN PERCY, M.D., F.R.S., F.G.S.,
LECTURER ON METALLURGY AT THE ROYAL SCHOOL OF MINES, LONDON, AND TO THE
ADVANCED CLASS AT THE ROYAL ARTILLERY INSTITUTION, WOOLWICH;
HONORARY MEMBER OF THE INSTITUTION OF CIVIL ENGINEERS,
AND OF THE SOCIETY OF ENGINEERS, LONDON.

INTRODUCTION, REFRACTORY MATERIALS, AND FUEL.

Revised and greatly enlarged Edition.

WITH ILLUSTRATIONS, DRAWN TO SCALE, 112 ON WOOD AND 9 ON STONE.

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1875.

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*This Work will consist of Volumes on the following
subjects:—*

INTRODUCTION, REFRACTORY MATERIALS, FIRE-CLAYS,
CRUCIBLES, FIRE-BRICKS, FUEL, WOOD, PEAT, COAL,
CHARCOAL, COKE, ETC. NEW EDITION [*Now Ready.*
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PLATINUM, AND OTHER METALS APPLIED IN THE
ARTS [*In Preparation.*

BY THE SAME AUTHOR.

THE MANUFACTURE OF RUSSIAN SHEET-IRON. WITH
ILLUSTRATIONS. 8vo. 2s. 6d.

PREFACE.

THE first of the series of volumes on Metallurgy, by the Author, was published in 1861, and treated of the following subjects:—Certain Physical Properties of Metals, General Considerations on Metallurgical Processes, Refractory Materials, Fuel, Copper, Zinc, and Brass. The three last-named subjects are special in their character, while the others are general, and may be regarded as introductory to the subject of Metallurgy. It was originally intended that all the above-mentioned subjects should be comprised in this volume, and it was not until after a considerable portion of it had been printed off, that it was decided to publish the special subjects, Copper, Zinc, and Brass, in a separate volume, on the ground that a single volume containing them all would have been inconveniently large.

The volume is complete in itself: it is not merely a new edition of what has been previously published by the Author, but is in great measure a new work, containing more than three hundred additional pages of fresh matter, and several articles on fresh subjects.

As the question of the utilization of peat, and the possibility of substituting it for coal in metallurgical and other manufacturing processes, have of late particularly engaged public attention in this country, I have endeavoured to collect and place before the reader in a condensed, and, I hope, intelligible form, such evidence as may enable him to arrive at a satisfactory judgment on that question.

Glowing prospectuses have from time to time appeared, inviting investments in peat-utilizing schemes, which may mislead the unwary and prove financially disastrous. The failure of such schemes has unhappily been too often recorded. However, in my judgment, there is a future for peat, but only under particular conditions, which I have specified.

The article Coal contains much additional and not a little new matter. More than one hundred and fifty analyses of coals, British and foreign, which have been made in the Metallurgical Laboratory of the Royal School of Mines, only a few at the national cost, are now published for the first time. Many of these analyses will, I conceive, be interesting in a scientific as well as practical point of view; and some of them, I think,

deserve careful consideration from the geologist. It may be thought that a more fitting vehicle of publication for at least the analyses of foreign coals might be found than this volume. I do not, however, share that opinion, as in the course of my experience, now pretty long, questions have frequently arisen as to the occurrence of mineral fuel in various parts of the world, with a view to the possibility of introducing metallurgical operations there with reasonable hope of success. The attention of the reader should be specially directed to the fact of the existence of enormous stores of coal, of various kinds and of excellent quality, in China; and the day seems to be not far distant when the development of the Chinese coal-fields will begin in earnest. Not only does that vast empire possess coal, but metalliferous ores in abundance, and hereafter it will certainly become one of the greatest metal-producing countries in the world.

There is no account in this volume of Coal-washing, a subject the knowledge of which is of great importance in the United Kingdom, and which to be properly treated would require a volume, with numerous costly illustrations, to itself. Possibly, I may hereafter attempt to produce a supplementary volume on this subject.

I have much pleasure in stating that in passing this volume through the press I have had the advantage of the assistance of my friend Mr. Channell Law, an Associate of the Royal School of Mines, who, during a period considerably exceeding twelve months, has devoted himself to the work with an energy, laborious perseverance, and goodwill which demand my warmest acknowledgment. I am further indebted to him not only for many valuable suggestions, critical remarks, and improvements in arrangement, but also for preparing several articles and notices, especially those concerning Calorific Intensity, Pyrometers, Siemens' Furnace, Coppée's Coke Oven, and Concluding Observations on Fuel. If the volume had been his own, he could not have shown a more earnest desire to render it as accurate and as useful as possible; and it is not going beyond the truth to add that he has greatly lessened my labour.

I have also pleasure in acknowledging the valuable assistance of Mr. William Prim in supervising the execution of the lithographic illustrations and some of the woodcuts. The assistance which I have received from other sources will be found duly acknowledged in the course of the volume.

JOHN PERCY.

March, 1875.

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ERRATA.

- Page 23. Figs. 1 and 2 are drawn to the scale of one-half, as indicated by the dimensions given, and the cylinders are not of the exact dimensions used at the arsenal at Woolwich, as stated in the text.
- " 24, line 5, *for* dependant, *read* dependent.
- " 218, line 27, *omit* the comma after the word 'evolved.'
- " 284, in the first column of the table, *insert* an asterisk after the letter *g*; thus—II. *g**.
- " 285. The footnote at the bottom of the table should read thus—"II. *d*, *e*, *f*, and *g* are reported in the Journal für praktische Chemie, 1872, cxiii. 416. Meyer conjectures that butylene may have been present."
- " 340, line 5 from bottom, *for* Stromberg, *read* Stormberg.
- " 385, line 3, after the words 'conical channel' *insert* the reference letter 'D,' shown in fig. 53.
- " 497, line 27, *omit* the word 'both.'
-

NOTE.—There are two or three references to information to be given in connection with the subject of Copper, which were inserted before the change of plan, mentioned in the first paragraph of the Preface, was adopted. Since this volume does not include the subject of Copper, these references are now out of place.

TABLE OF THE SYMBOLS AND ATOMIC WEIGHTS OF VARIOUS
ELEMENTARY BODIES REFERRED TO IN THIS VOLUME.

| Name. | Symbol. | Atomic Weight. | |
|------------------|---------|----------------|-------|
| | | Old. | New. |
| Aluminium | Al | 13·75 | 27·5 |
| Barium | Ba | 68·5 | 137 |
| Calcium | Ca | 20 | 40 |
| Carbon | C | 6 | 12 |
| Chlorine | Cl | 35·5 | 35·5 |
| Copper | Cu | 31·75 | 63·5 |
| Fluorine | F | 19 | 19 |
| Gold | Au | 196·7 | 196·7 |
| Hydrogen | H | 1 | 1 |
| Iron | Fe | 28 | 56 |
| Magnesium | Mg | 12 | 24 |
| Manganese | Mn | 27·5 | 55 |
| Nitrogen | N | 14 | 14 |
| Oxygen | O | 8 | 16 |
| Phosphorus | P | 31 | 31 |
| Platinum | Pt | 98·55 | 197·1 |
| Potassium | K | 39·1 | 39·1 |
| Silicon | Si | 21 | 28 |
| Sodium | Na | 23 | 23 |
| Strontium | Sr | 43·75 | 87·5 |
| Sulphur | S | 16 | 32 |
| Titanium | Ti | 25 | 50 |

NOTE.—The formulae, corresponding to the old atomic weights, used in the first edition of this volume, have been retained in the present one; and formulae, corresponding to the new atomic weights, have been added within *thick* brackets. When the introduction of the new atomic weights has not necessitated any change in the formula, the word “idem” has been inserted within the brackets, instead of the formula being repeated.

METALLURGY.

ERRATUM.

Page 165. In the Table of the Calorific Power of various Substances, iron is stated to have a calorific power of 4134; which statement is erroneous. Andrews found that the amount of heat produced by the combustion of a certain weight of iron by one gramme of oxygen is equal to that required to raise 4134 grammes of water 1° Centigrade. (Phil. Mag., s. 3, 1848, xxxii. 335.) Hence, assuming magnetic oxide to have been the product of such combustion, the calorific power of iron would be 1575. But there is reason for doubting the correctness of this assumption; for, according to Marchand, the substance formed, when iron in a compact state is burnt in oxygen gas, may be represented by the formula, Fe^{O} .

cesses relate to chemistry and physics, and as mechanical appliances of various kinds are employed in these processes, it follows that the sciences of chemistry, physics, and mechanics must be the foundation of the science of metallurgy. In order, therefore, that the student may with advantage enter upon the study of metallurgy, it is essential that he should possess a considerable amount of preliminary knowledge.

Lampadius remarks that, "if the metallurgist is not content to remain a mere empiric, it is necessary that he should study several accessory sciences, especially if he aspires to the direction or management of works. He must acquire a knowledge of mathematics, physics, chemistry, mineralogy, mining, architecture, the cultivation of forests, drawing, finance, and political economy, some in their whole extent, and others only in part with reference to special objects."² This, it must be admitted, is a pretty comprehensive list

¹ I am indebted to my friend, Dr. William Smith, D.C.L., LL.D., for this statement.

² *Grundriss einer allgemeinen Hüttenkunde*, Göttingen, 1827, p. 5.

of subjects, and is calculated to excite not a little apprehension in the mind of the metallurgical student when he commences his labours.

As the word science in relation to manufacturing art is often vaguely used, it may be well to give the following illustration of its meaning. When an ore of copper, consisting essentially of copper, iron, sulphur, and silica, is subjected to a series of processes, such as heating with access of air under special conditions, melting, etc., copper is separated in the metallic state. The sum of these processes is termed the *smelting* of copper. In this operation of smelting, certain chemical changes take place: the sulphur combines with the oxygen of the air, and is evolved chiefly as sulphurous acid; the iron is similarly converted into oxide, which combines with the silica present, and forms a fusible compound or slag. There are thus several facts which are proved by chemical evidence. These facts, when systematically arranged, may be said to constitute the scientific knowledge of copper-smelting; and that knowledge implies necessarily a knowledge of the chemical relations of copper, iron, sulphur, oxygen, and silica to each other. There are many other facts connected with copper-smelting, but those mentioned suffice for the purpose of illustration. The man who conducts the process of copper-smelting in ignorance of these facts, has simply an empirical, in contradistinction to a scientific, knowledge of the art.

The history of metallurgy dates from the remotest antiquity; and, as Le Play correctly observes, "most of the fundamental phenomena of metallurgy were discovered and regularly applied to the wants of man before the physical sciences properly so called existed."³

The term metal, like the term acid, is rather conventional than strictly scientific. Formerly, when science was much less advanced than at present, the metals constituted a well-defined class of elements. The properties which were regarded as specially characteristic of metals were physical, and were not, as at present, founded on chemical relations. Thus lustre, *sui generis*, and high specific gravity were considered to be essential characters of all metals. But we are now acquainted with metals which have a lower specific gravity than water, and with non-metallic elements which present a bright metallic lustre: sodium and lithium are examples of the former, while carbon in the state of graphite and crystallized silicon are examples of the latter.

By far the greater number of the elementary bodies at present known are metals.

In this work only those metals will be considered which are the subjects of extraction on a manufacturing scale; and of such the number is comparatively limited.

³ Description des Procédés métallurgiques employés dans le Pays de Galles pour la Fabrication du Cuivre. Paris, 1848.

ON CERTAIN PHYSICAL PROPERTIES OF METALS.

PHYSICAL STATE.

THEY are all solid, excepting mercury, which is liquid, at the ordinary temperature of the atmosphere.

ACTION OF HEAT.

The following is a convenient practical classification of the metals, founded on their degree of fusibility,⁴ with examples of each class:—

FUSIBLE BELOW REDNESS.—Tin, lead, and bismuth.

FUSIBLE ABOVE REDNESS, BUT AT TEMPERATURES EASILY ATTAINABLE IN FURNACES.—Silver, copper, and gold.

FUSIBLE ONLY AT THE HIGHEST TEMPERATURES ATTAINABLE IN FURNACES.—Iron, nickel, and manganese.

PRACTICALLY INFUSIBLE, AT LEAST IN ORDINARY FURNACES.—Platinum and iridium.

It must, however, be admitted that the language commonly used to indicate high temperatures, such as red-heat, white-heat, &c., is far from satisfactory, as, in judging of temperature by the eye, much may depend upon the susceptibility of the retina of the observer to light, as well as upon the degree of illumination under which the observation is made.

Ponillet has employed an air-thermometer provided with a bulb of platinum to determine high degrees of temperature; and by this means has arrived at the following results:—⁵

| | | |
|-----------------------------------|--------------|---------------|
| Incipient red-heat corresponds to | 525° C. | 977° F. |
| Dull red | 700 | 1292 |
| Incipient cherry-red | 800 | 1472 |
| Cherry-red | 900 | 1652 |
| Clear cherry-red | 1000 | 1832 |
| Deep orange | 1100 | 2012 |
| Clear orange | 1200 | 2192 |
| White | 1300 | 2372 |
| Bright white | 1400 | 2552 |
| Dazzling white | 1500 to 1600 | 2732 to 2912* |

* Mr. Hopkins, of Cambridge, has shown that, when certain bodies are subjected to great pressure, they require a higher temperature for fusion. Brit. Assoc. Rep. 1854. The freezing-point of water, on the contrary, is lowered by pressure: thus, a pressure of 133·66 atmospheres reduces the temperature at which water freezes 1° C. Poggendorff's Annalen, 1858, cv. 161.

⁵ Comptes rendus, 1836, iii. 782.

⁶ Expensive litigation has been caused by the application of terms commonly used

to indicate temperature. Thus in the specification of one patent it was directed that a particular operation should be carried on at a dull red-heat, and in the specification of another patent stress was laid on the temperature of cherry-redness. Both of these patents came before the Law Courts, and one of the grounds on which their validity was disputed was the indefiniteness of the expressions above mentioned. For the reason given in the text the witnesses differed on those points.

Metals are either volatilized or not volatilized by heat: the former are designated *volatile* and the latter *fixed* metals. The following metals may be mentioned as examples of each class:—

VOLATILE METALS.—Zinc, cadmium, and arsenic.

When arsenic is volatilized under ordinary atmospheric pressure, it passes directly from the solid to the gaseous state, like camphor; and not through the intermediate state of fusion, like zinc and cadmium.

FIXED METALS.—Iron, copper, and gold.

It is important to note that the word *fixed* is merely comparative and conventional. Thus, a metal which may be heated *per se* in furnaces, even the most powerful, without losing sensibly in weight, and which is, therefore, in a practical point of view, regarded as fixed, may yet be volatilized at very high temperatures, such as are attained by concentrating the solar rays in the focus of a mirror or lens, by the voltaic current, or by the combustion of hydrogen by oxygen.

M. Despretz has published some interesting experiments on the production of intense heat, by employing in conjunction the heat derived from the solar rays, the oxy-hydrogen blowpipe, and a powerful voltaic battery. It is stated that the temperature produced from this triple source of heat sufficed immediately to volatilize magnesia in the form of white vapour, and to melt anthracite. It is further asserted that, by the action of a very powerful Bunsen's battery alone, even carbon was melted, volatilized, and condensed in the state of black crystalline powder; silicon, boron, titanium, and tungsten were melted; and 250 grms. (3858 grs.) of cuttings of platinum were melted in a few minutes.⁷ In the first edition of this volume it was announced that Deville and Debray had succeeded in melting as much as 25 kilogrammes (55 lbs. avoird.) of platinum at a time by the heat resulting from the combustion of coal-gas by oxygen in a small closed box-like furnace of iron lined with lime.⁸ But subsequently, in the London International Exhibition of 1862, there was an ingot of platinum, weighing 2½ cwt., which had been melted in the same manner. In company with Faraday, I had the pleasure of seeing Deville melt about 600 ounces of platinum by this means, in the laboratory of Messrs. Johnson and Matthey.

Iron has the valuable property of continuing sufficiently soft and plastic through a considerable range of temperature below its actual melting-point, to admit of its being easily *welded*; whereas many metals pass quickly, when heated, from the solid to the liquid state. The quality of welding appears to be related to that of softness in a metal. In this soft state two pieces of iron may be made to unite by compression, or, in other words, may be welded together. In the process of welding the metal is never in a state

⁷ Comptes rendus, 1849, xxviii. 755; 1849, xxix. 48, 545, 709.

⁸ Ibid. 1860, l. 1038.

of absolute fusion, as is the case in the process designated *autogenous soldering*. When the edges of two pieces of sheet-lead are brought together, they may be easily and solidly united, either by applying the flame of a blow-pipe along the line of contact, or a piece of red-hot iron, as in the operation termed *burning*. The union of the edges so effected is due to actual fusion of the metal. But the difference between welding and autogenous soldering is only one of degree. If two pieces of lead or other metal were heated just enough to render them soft or somewhat pasty, they could be made firmly to unite by pressure, just like iron when in a similar physical state; and to such a case it would be strictly correct to apply the term welding. Lead is so soft at the ordinary temperature that two freshly cut and perfectly bright plane surfaces of this metal may be made to cohere pretty firmly by compression; and when it is in the state of fine powder, its particles, provided they are free from tarnish or intermixed solid matter, may be condensed by pressure into a solid mass. Medals have thus been made from the powder of lead. Medals of gold, silver, and copper have also been made in the same manner from the powders of those metals, separate or intermixed. All such cases, it has been suggested, should be regarded as essentially cases of welding.

EFFECT OF INTENSE COLD.—Fritzsche, of St. Petersburg, observed in that city, at the beginning of the year 1868, that certain blocks of tin became disintegrated and crumbled into fragments, which for the most part seem to me to resemble in form, though smaller in dimensions, the columnar pieces produced when a pig of lead or block of tin is heated to a certain degree and struck with a hammer.⁹ He conjectured that this result might be due to the severe frost which then prevailed, and tested the truth of his conjecture by experiment. He exposed portions, cut from a block of the same kind of tin, to a temperature ranging from -40°C . to -43.75°C ., and found that they became disintegrated exactly like the blocks in question. It was necessary to prolong the exposure to this intense cold during several hours in order to produce the effect, which was accompanied with the appearance of button-like prominences of a steel-grey colour on the surface of the tin. Each prominence, he supposes, represents a centre from which crystallization proceeds, and "gradually the meeting of the acicular crystals produces fissures at the points of contact, and the fragment, the volume of which is much augmented, falls in pieces, which are very friable and crumble between the fingers. A remarkable fact is that elevation of temperature causes the steel-grey colour to disappear. This may be shown by plunging the steel-grey tin (enclosed in a sealed glass tube) into hot water, when the natural white colour reappears, but without the former metallic lustre. This change of colour is not attended by a loss of weight; neither is the transition of cast-tin into the crystalline modification, in the presence of air

⁹ I have a specimen of the tin thus crumbled, which Fritzsche examined, for which I am indebted to Mr. W. C. Roberts, Chemist to the Mint.

or in alcohol, attended with any loss of weight." The kind of tin, which was the subject of these observations and experiments, was that known in commerce as Banca tin, from the locality where it is produced; but English tin, which he also subjected to similar experiments, did not suffer any disintegration. Banca tin suffered the same change after being re-melted. Fritzsche decided to investigate the subject further, and to analyse this tin.¹

More recently Dr. Oudemans has called attention to another instance of disintegration, in the case of some blocks of tin (found to contain only 0.3 per cent. of impurity), which were sent by rail from Rotterdam to Moscow in the winter of 1871, and arrived at their destination "in the form of a powder consisting of large crystalline grains." Dr. Oudemans attributed this result to the combined action of cold and vibration.²

P. Lewald maintains that the disruption of the tin depends upon the mode of casting, and not upon any special physical property; and he asserts, that when a cast bar of the same kind of tin, about 1 square inch in cross-sectional area, is passed once through rolls used for rolling round-iron, a piece cut from the rolled bar may be exposed to -40°C . without showing the phenomenon in question.³

SPECIFIC GRAVITY.

The specific gravity of metals at the ordinary temperature ranges between 0.6⁴ and 21.5.⁵ It varies within certain limits with the special molecular condition of the metal consequent on previous treatment. The processes of hammering, rolling, and stamping tend permanently to increase the specific gravity of metals in the state in which they exist after fusion, by the closing up of air-holes and of void space resulting from the solidification and contraction of the interior of the mass after the solidification of the exterior. But so far from compression permanently increasing the specific gravity of a *perfectly solid* metallic mass, the contrary is the case, at least with certain metals. Thus, it has been proved by experiment that when sheets of copper and iron are subjected to further rolling *without annealing*, their specific gravity is slightly diminished.⁶ The metal is thereby hardened, and a state of strain or tension is induced amongst its particles. According to Marchand, the specific gravity of bismuth is permanently diminished by subjecting this metal to great pressure; but Dr. Tyndall informs me that he has not been able to verify this statement by experiment with a small hydraulic press. In recording the specific gravity of a metal, it is important in every case to specify the treatment which it may have previously received, as well as the temperature

¹ Phil. Mag. s. 4, Sept. 1869, xxxviii. 207.

² Revue hebdom. de Chim. scient. et indust. 1872, iii. 557.

³ Dingler's Polytechnisches Journal, 1870, cxvi. 369.

⁴ Sp. gr. of lithium as determined by Bunsen.

⁵ Sp. gr. of fused platinum, Deville, Ann. de Chim. et de Phys. s. 3, 1859, lvi. 420.

⁶ See the article on the Specific Gravity of Copper in the sequel.

at which the observation was made; for otherwise the results of different observers cannot be satisfactorily compared.

CRYSTALLIZATION.

The brittle metals in common use always exhibit a well-marked crystalline structure. This is especially the case with zinc, antimony, and bismuth, upon the fractured surfaces of which distinct crystalline planes may be seen; but it may be demonstrated that masses of metals, solidified after fusion, such as lead and tin, which are too soft to admit of being fractured by a blow at the ordinary temperature, consist of aggregations of crystals.

The metals, so far as observations have extended, have been found to crystallize either in the *cubic*, *pyramidal*, or *rhombohedral* systems: thus gold, silver, lead, copper, and iron occur either in cubes, the regular octahedron, or rhombic dodecahedron; while tin belongs to the pyramidal system, and bismuth to the rhombohedral.

The conditions under which metals generally crystallize are as follow:—

ON SOLIDIFICATION AFTER FUSION;

BY CONDENSATION FROM THE STATE OF VAPOUR;

BY ELECTROLYTIC DECOMPOSITION OF METALLIC SOLUTIONS.

SOLIDIFICATION AFTER FUSION.—Slowness of cooling is, as might be expected, the condition favourable to crystallization. Thus an ingot of zinc, when allowed to cool very slowly, presents much larger crystalline faces on the fractured surface than when cooled quickly. The same fact is also strikingly exemplified in grey pig-iron when similarly treated. When one portion of this metal is allowed to run from a furnace upon a cold slab of iron, so as to be cooled with extreme rapidity, and another portion is allowed to run under a mass of hot slag, so as to be cooled with extreme slowness, the fracture of the latter will be much more largely crystalline than that of the former; so much so as to make it difficult to believe that the two portions of metal should have flowed simultaneously from the same furnace.

If it is desired to prepare a metal in a well-crystallized state after fusion, the usual process is to melt a considerable quantity of it in a crucible, and as soon as the surface has solidified to a slight depth, to break the crust, and as rapidly as possible pour out what remains liquid. When pure bismuth is thus operated upon, it will be left in beautiful crystals adhering to the sides and bottom of the crucible and to the under surface of the remaining part of the crust; but some dexterity is required to perform the operation successfully. It is remarkable how perfectly the liquid metal drains off from the crystals, thus showing that the latter are not *moistened*, so to speak, by the former, just as is the case when mercury is brought in contact with the bright surface of a metal with which it does not directly alloy. I have beautiful specimens of copper, brass, and iron, which have been so crystallized.

If molten lead is allowed to cool slowly, and is stirred from time to time, a period arrives when, owing to its partial solidification in the form of small crystals, it becomes a semi-fluid or pasty mass. The crystals, which have a higher specific gravity than the liquid metal, and consequently tend to subside, may be taken out and drained by means of an iron ladle perforated with numerous holes. This is actually done on the large scale in the well-known desilverization process of Pattinson.⁷ When the lead is left to solidify without being disturbed, it presents no visible evidence of crystalline structure. Crystals of tin may be obtained in a similar manner with equal facility.

When a metal has been rolled, and thereby acquired a more or less fibrous structure by the extension of its component crystals in one direction, it may become largely and distinctly crystalline by long exposure to a temperature far below its melting-point, or by short exposure to a temperature near, yet sensibly below, its melting-point, as is the case with iron, and especially with zinc. The particles of the metallic mass when so heated obtain sufficient freedom of movement to act in obedience to crystallogenic force, and they accordingly arrange themselves in definite geometrical forms, or, in a word, they crystallize. The two metals, iron and zinc, are mentioned by way of illustration, simply because the action of heat upon them has been particularly investigated, and not because they are to be regarded as exceptional with respect to that action. It may be safely predicted that what is true of those metals under the conditions above specified will hereafter be found to be equally true of other metals capable of being treated in a similar manner.

If heat be regarded as a kind of vibratory movement of the particles of matter, then, in one sense, the crystalline structure, which is induced in a metallic mass by long exposure to heat at a temperature sensibly below its melting-point, may be said to result from vibration; and hence the question naturally arises, whether a similar result will follow the vibration produced by concussion, friction, or other simple mechanical action. This is a question which has been much debated by engineers, but without leading to a satisfactory conclusion. What is wanted is an extended experimental investigation of the subject by thoroughly competent observers; for at present, instead of substantial facts, there is little else than mere opinion and vague belief. Such, however, does not seem to be the view of M. de Villeneuve-Flayosc, who takes for granted the very points in dispute, and thus expresses himself:—" . . . The particles of vibrating bodies preserve a mobility, which permits crystallization, metamorphism [i.e. of rocks, etc.], and regularity of sub-divisions; and this regularity establishes itself whatever may be the time of the periods of oscillation; it is the mathematical consequence of the law of *least action*. Under the influence of reiterated trepidations, the iron of

⁷ See the volume on the Metallurgy of Lead, by the Author, pp. 121 *et seq.*

rails on railways and the axle-trees of wheels takes a crystalline structure The molecular movements caused by cold render iron crystalline and brittle; renewed explosions in cannons modify the cohesion of metallic masses, and determine the final rupture. M. Kuhlmann has seen tenacious and fibrous iron-plate, forming the shell of steam-boilers, become brittle and crystalline under the tremblings (*frémissements*) of evaporation. [This is an extraordinary statement, which is certainly opposed to general experience.—J. P.] All metals present this molecular mobility. The densest and the most refractory of all, platinum [which, however, is not the most refractory.—J. P.], acquires crystalline structure when it forms vessels filled with boiling liquid. . . . Watchmakers know that springs which are new and irregular in action become isochronous after repeated vibrations. Dealers in musical instruments assert that organic and inorganic plates, after having been used acoustically for a certain time, become more sonorous, and, consequently, more easily and more regularly divisible.”⁸

CONDENSATION FROM VAPOUR.—When arsenic is volatilized, it condenses in the form of a crystalline crust. The vapour of zinc will likewise condense in a distinctly crystalline form.

ELECTROLYTIC DECOMPOSITION.—Metals, when separated in the metallic state from a solution of their salts by the voltaic current, generally occur more or less distinctly crystallized. A current of low intensity, so long as it is capable of effecting the decomposition, is the condition favourable to the development of distinct crystals. On the contrary, a metal may be precipitated in the state of apparently amorphous powder by a current of great intensity. The metal will appear at the pole at which hydrogen would be evolved on the electrolytic decomposition of water.

VARIETIES OF FRACTURE.

Except when otherwise stated, the fractured surface is supposed to be that produced in the metals at the ordinary temperature of the atmosphere.

The chief varieties of fracture are the following:—

CRYSTALLINE.—Characteristic examples of this fracture are presented by zinc, antimony, bismuth, and the variety of pig-iron termed *Spiegeleisen* by the Germans, from the fact of its fractured surface presenting large, bright, mirror-like crystalline faces.

GRANULAR.—Grey forge pig-iron affords an instance of this kind of fracture, which only differs from the last in the smaller size of the crystals, and which may be divided into *coarse* or *fine* according to degree.

FIBROUS.—When an ordinary bar of good wrought-iron is broken while cold by bending it backwards and forwards—or, in the case of

⁸ Sur la Cause de l'Harmonie des Formes terrestres, Comptes rendus, 1865, lxi. 15.

a thick bar, by cutting a nick across it, and then bending it so that rupture may take place along the line of the nick,—the fractured surface presents a fibrous appearance. Much stress is laid upon the “fibre” of iron thus manifested on fracture; and according to the character of the fibre a judgment is formed as to the quality of the iron.

SILKY.—This is only a fine variety of the fibrous. When a small piece of tough copper is bent backwards and forwards until it breaks, the fractured surface will appear finely fibrous and present a silky lustre. The fibre in this case seems to be entirely produced by the repeated bending which is necessary to cause rupture; for when a large bar or ingot of tough copper is broken in the usual manner by nicking it sufficiently across one surface, supporting it at its ends with the nick downwards and then striking it with a sledge-hammer on the part opposite the nick, the fractured surface is crystalline-granular and not fibrous. But in the case of bar-iron it may be shown that a fibrous structure pre-exists, and, therefore, that the fibrous appearance of its fractured surface can only be partially due to the process of bending backwards and forwards. When a bar of wrought-iron is exposed during a sufficient length of time to the action of dilute sulphuric or hydrochloric acid, it will be, as it were, dissected, and will then present the appearance of being composed of a bundle of parallel fibres; but if the bar is melted and the melted metal similarly acted upon, a *crystalline* and *not a fibrous* appearance will be produced. The subject of the fracture of iron will be found treated at considerable length in the second volume of this work, on Iron and Steel.

COLUMNAR.—When some of the malleable metals are heated to certain degrees not far from their melting-points and then struck with a hammer or allowed to fall on the ground from a sufficient height, they easily break into columnar pieces similar in form to common starch. The peculiar form of the grain-tin of commerce is produced in this manner. When a pig of lead, or an ingot of copper or brass, is heated to a certain degree, it easily breaks under the blow of a heavy hammer, and presents a columnar fracture. In the case of lead, the purer the metal, the more largely columnar, *ceteris paribus*, is the fracture.

VITREOUS.—The fracture of certain very brittle alloys is distinctly glass-like, even when they are allowed to solidify slowly after fusion. An alloy consisting of 2 parts of zinc and 1 part of copper furnishes a good illustration of this fracture, and so does copper when combined with a considerable proportion of silicon, say exceeding 5 per cent. Very fine-grained hard steel, steel alloyed with tungsten, and speculum-metal, which is an alloy of copper and tin containing about 30 per cent. of the latter metal, exhibit a more or less vitreous fracture.

ELASTICITY.*

Suppose a steel rod AB , fixed at the end A , has a pulling force, or, what is synonymous, a traction force, applied to it at the other end B , operating in the direction of the axis, it will be lengthened, say from B to B' . On the cessation of the pulling force, the rod will either be reduced to its original length or remain elongated to some point between B and B' . This property of lengthening and shortening, under the conditions stated, is the property of elasticity. If the rod is stretched to the utmost limit without undergoing permanent elongation, or, as engineers term it, permanent "set," after the removal of the pulling force, then, supposing B' to be that limit, the distance from B to B' is defined as the *limit of elasticity*.

Conversely, suppose a compressing force is applied to the rod at the end B , and the axis to remain straight, then the rod will be shortened, say from B to B_1 ; and on the cessation of the compressing force, it will either be extended to its original length or remain shortened to some point between B and B_1 . What has been stated with respect to the limit of elasticity in the case of a pulling force applies, conversely, to that of an opposite or compressing force.

The elongation caused by a pulling force is equal to the contraction caused by a compressing force of equal power. Every part of a homogeneous rod of the same dimensions throughout undergoes equal elongation, and the total elongation is, therefore, proportionate to the length of the rod.

The amount of elongation or contraction which may occur in any body, subjected to the conditions above mentioned, can only be ascertained by actual experiment upon that particular body, as different bodies differ widely from each other in degree of elasticity.

The lengthening or shortening of a rod by the application of a pulling or compressing force is the simplest of all the problems of elasticity.

Elongation is in the inverse ratio of the sectional area of the rod, for the force is distributed equally over every part of that area. Whatever be the *form* of the sectional area, so long as its *size* remains the same, the same degree of elongation, or, conversely, of contraction,

* In writing on the subject of elasticity, I have particularly availed myself of the following sources of information:—Cours de Physique de l'École polytechnique, par M. J. Jamin, ancien Élève de l'École normale, Professeur de Physique à l'École polytechnique; 1858, i. 129 et seq.:—Recherches sur l'Elasticité, par M. G. Wertheim, Ann. de Chim. et de Phys. s. 3, 1844, xii. 385 et seq., and 1845, xv. 114 et seq.:—Recherches expérimentales sur l'Elasticité des Métaux, faites à l'Observatoire physique central de Russie, par A. T. Kupffer, Directeur de l'Observatoire physique central et membre de l'Académie

des Sciences de St.-Petersbourg; i. 1860;—The Elasticity, Extensibility, and Tensile Strength of Iron and Steel, by Knut Styffe, Director of the Technological Institute at Stockholm; translated from the Swedish by Christer P. Sandberg; 1869. It is not intended to present here more than a very general view of this interesting and important subject, so that, for further and accurate information respecting it, the reader is referred to the works above mentioned and various papers in the Transactions of scientific societies. In Wertheim's memoir numerous references to such papers are given.

will result from the application of the same force. Hence, if the area be doubled, the elongation or contraction, as the case may be, will be reduced by half under the operation of an equal force; for the conditions are the same as if the single rod had been replaced by two rods of the same dimensions. The truth of this proposition, deduced *à priori*, has been demonstrated by experiment.

Elasticity may be estimated by the force, which, acting upon a unit of transverse sectional area, would produce an elongation equal to unity, or, in other words, would double the length of a rod.

This force, which is termed the *coefficient or modulus of elasticity*, varies for every different body; it is purely hypothetical, as only such a substance as caoutchouc could be stretched to twice its own length without breaking or becoming permanently elongated. The metre, kilogramme, and square millimetre may be conveniently accepted as the units of length, of force, and of sectional area, respectively. But in this country the square inch is usually taken as the unit of sectional area, the linear foot as the unit of length, and force is usually estimated in pounds avoirdupois.

Kupffer estimates elasticity (which he terms *linear elastic dilatation*) by the elongation in millimetres which a wire 1 metre long and 1 millimetre square in sectional area receives when it is subjected to the traction force of 1 kilogramme.

To recapitulate: when the limit of elasticity of a body is not exceeded, the elongation, e , is proportional, *directly* to the length, l , of the rod and to the stretching force, P , and *inversely* to the sectional area, a . It is also *inversely* proportional to the modulus of elasticity, E , since the *greater* the (hypothetical) force required to double the length of the rod, the *less* will be the elongation under the action of a given stretching force.¹ The following formula conveniently expresses these facts:—

$$e = \frac{Pl}{aE}$$

Example.—A silver wire 5 metres in length, and 3 sq. mm. in sectional area, is stretched by a force of 10 kilogr. What elongation will it undergo?

The modulus of elasticity of silver wire is approximately 7400 kilogr. per sq. mm. of sectional area. Hence the elongation will be 2.25 mm., as shown by the following calculation:—

$$\begin{aligned} e &= \frac{10 \times 5}{3 \times 7400} \\ &= 0.00225 \text{ metre} \\ &= 2.25 \text{ mm.} \end{aligned}$$

The formula for ascertaining the coefficient or modulus of elasticity may be deduced as follows:—²

¹ I have not noticed in the text the distinctions between perfectly and imperfectly elastic bodies, as it would probably result in too lengthy a discussion.

² Styffe, *The Elasticity, etc., of Iron and Steel*, p. 54.

Let L and L' represent the lengths of a rod or wire when acted upon by the traction forces P and P' , forces which occasion no sensible permanent elongation; l its original length; a its sectional area; and E the coefficient or modulus of elasticity; then,

$$L - l = \frac{Pl}{aE} \text{ and } L' - l = \frac{P'l}{aE}$$

$$\text{whence, } L' - L = \frac{P' - P}{aE} l$$

$$\text{and, therefore, } E = \frac{P' - P}{L' - L} \cdot \frac{l}{a}$$

Example.—A copper wire 10 metres in length, and 0.5 sq. mm. in sectional area, is stretched 16.4 mm. by a weight of 10 kilogr., and 24.6 mm. by a weight of 15 kilogr. What is the coefficient of elasticity of the wire?

$$\begin{aligned} E &= \frac{15 - 10}{10024.6 - 10016.4} \times \frac{10000}{0.5} \\ &= \frac{5}{8.2} \times 20000 \\ &= 12195 \text{ kilogr.} \end{aligned}$$

In determining the elasticity of a metal by the method of elongation, Wertheim proceeded as follows:³—A rod or wire of the metal, made as straight as possible, say 1 metre in length and from 3 to 10 millimetres in diameter, is suspended vertically from a fixed point, and to the lower end a weight is attached, the wire having been previously marked at two points about 80 centimetres apart. The preliminary straightening is never perfect, and, in consequence, after the first application of the weight, slight permanent elongation, due to straightening, is always observed. The length of the wire between the two marks, when it has been loaded with a weight sufficient to straighten it, is exactly noted, and this load forms the starting-point for the subsequent experiments. The weight is increased by relatively small additions, and 5 or 10 minutes after each addition, when equilibrium is re-established, the distance between the two marks on the wire is measured, after which the weight is raised and the distance is again measured. This operation is repeated until the wire begins to be sensibly and permanently lengthened; but Wertheim remarks, that “measurement now becomes more difficult, for elastic bodies seem no longer to attain truly stable equilibrium, and the final elongation due to the load cannot be ascertained. A wire of cadmium, even after the action of a weight during eight days uninterrupted, had not ceased to elongate.”

The elongation, which is caused in a metallic wire by any load whatever, is composed of three values, namely: instantaneous elongation, which disappears immediately after the removal of the load; supplementary elongation, which occurs when the load acts for a

³ Ann. de Chim. et de Phys. s. 3, 1844, xii. 403.

long time, say, during several days, and which also disappears after the removal of the load, but only gradually in the course of several days; constant elongation, which does not disappear after the removal of the load, even after the lapse of several days (Kupffer).

When permanent elongation begins under the influence of a traction force, the temperature of the metal rises; so that in experiments on this subject, it is necessary to bear the fact in mind, and adopt expedients to keep the temperature uniform.⁴ As the actual limit of elasticity cannot be exactly determined by experiment, the weight which produces a permanent elongation of 0·00005 per cent. is conventionally accepted by Wertheim and others as expressive of the limit. But, with respect to this conventional limit, Styffe remarks, that in dealing with bars of iron and steel, this limit cannot generally be ascertained with any degree of accuracy: because, in the first place, such bars as they come from ironworks are rarely so true as not to require straightening before subjecting them to experiment; and it is scarcely possible to perform the operation of straightening without leaving some degree of curvature, which, even though it may be very small, renders it difficult, if not impossible, to measure their length with absolute precision; and, because in the second place, if a bar should be elongated 0·00005 per cent. in length by a traction force acting, say, for one minute, the same elongation might also result from a smaller force acting during a longer time, or from the successive additions of several smaller forces, which latter condition must always exist in experiments for ascertaining the limit of elasticity. Hence, the limit may vary notably with the method employed in its determination.⁵

The coefficient of elasticity is not constant for the same metal, but increases when the specific gravity of the metal is increased, and conversely.

The elongation of rods or wires, by the application of loads, causes but very little change in their specific gravities; and, hence, the coefficient of elasticity also ought only to vary but very little in different positions of equilibrium, which is found to be the case so long as the load does not approximate very closely to that which produces rupture. The law of Gerstner, deduced from his experiments on steel wires, applies, according to Wertheim's results, to all metals, which, after having been stretched beyond their limit of elasticity, again sensibly attain a position of equilibrium. That law is as follows: a wire subjected to extension behaves in each fresh position of equilibrium as it did in its original state; not only do the elongations remain proportional to the forces applied, so long as the loads are insufficient to produce additional permanent elongation, but the proportional elongations produced by the same weights still remain the same in the different positions of equilibrium, so that there should be the same coefficient of elasticity, whether the limit of elasticity has or has not been surpassed.

Permanent elongation does not take place by leaps or jerks, but con-

⁴ Styffe, *The Elasticity, etc., of Iron and Steel*, p. 97.

⁵ *Ibid.* p. 29.

tinuously; by suitably varying the load and its duration, it is possible to produce such permanent elongation as may be desired (Wertheim).

Amongst Wertheim's conclusions are the following: "A true limit of elasticity does not exist, and if no permanent elongation is observed to result from the first loads, it is only because they have not been left to act during sufficient time, and because the rod subjected to experiment is too short relatively to the degree of accuracy of the instrument used for measuring. The limits of elasticity and of cohesion also depend much on the mode of operating: the former is found to be greater, and the latter less, in proportion to the slowness with which the load is increased." Hence it appears how arbitrary is the determination of the limit of elasticity and of the load required to produce permanent elongation. But, although it may not be practicable to ascertain by experiment the *exact* limit of elasticity; yet there must assuredly be such a limit in the case of metals, within which a force may operate during a very long, if not an indefinite period, without producing permanent elongation of practical importance; for, otherwise, metallic rods could not be used for the suspension of weight in such structures, for example, as the ordinary roofs of railway stations and suspension bridges.

Subjoined are two tables giving the modulus of elasticity of some of the principal metals in different physical states.

TABLE OF THE COEFFICIENTS OF ELASTICITY OF CERTAIN METALS, IN THE UNANNEALED AND ANNEALED STATES, AFTER HAVING BEEN DRAWN OUT INTO WIRE, FROM WERTHEIM'S OBSERVATIONS, MADE AT THE TEMPERATURE OF FROM 15° TO 20° CENTIGRADE. (Condensed from table in the Ann. de Chim. et de Phys. s. 3, 1844, xii. 441, 442.)

| Number. | Name of the Metal. | Specific Gravity found. | Coefficient of Elasticity | |
|---------|--|-------------------------|---|--|
| | | | in kilogr. per sq. mm. of sectional area. | in tons per sq. in. of sectional area. |
| I. | Lead, prepared by reducing the oxide obtained by calcining nitrate of lead: | | | |
| | After fusion | 11·215 | 1775 | 1127·0 |
| | Hard-drawn | 11·169 | 1803 | 1144·8 |
| | Annealed at 100° C. | 11·232 | 1727 | 1096·5 |
| II. | Gold, pure: Hard-drawn | 18·514 | 8131 | 5162·7 |
| | Annealed | 18·035 | 5584 | 3545·5 |
| III. | Silver, pure: Hard-drawn | 10·369 | 7358 | 4671·9 |
| | Annealed | 10·304 | 7140 | 4533·5 |
| IV. | Platinum, manufactured: | | | |
| | Hard-drawn wire of average thickness... | 21·275 | 17044 | 10891·3 |
| | Annealed | 21·083 | 15518 | 9853·1 |
| V. | Iron, containing 0·416 % of carbon and a trace of silica (<i>sic</i>): | | | |
| | Hard-drawn | 7·748 | 20869 | 13250·7 |
| | Annealed | 7·757 | 20794 | 13203·1 |
| VI. | Cast-steel, containing 1·495 % of carbon and 0·395 % of silica (<i>sic</i>): | | | |
| | Hard-drawn | 7·717 | 19549 | 12412·6 |
| | Annealed | 7·719 | 19561 | 12420·2 |

The specific gravities, above given, are certainly not in all cases correct, notably in that of lead.

TABLE OF THE COEFFICIENTS OF ELASTICITY OF CERTAIN METALS AT DIFFERENT TEMPERATURES. (Wertheim, *Ann. de Chim. et de Phys.* s. 3, 1845, xv. 119.)

| Number. | Name of the Metal. | Coefficient of Elasticity, in kilogr. per sq. mm. of section, as determined by the method of elongation, at the temperatures of the Centigrade scale given below. | | | | |
|---------|--|---|-------|-------------|-------|-------|
| | | -17° even to -10°. | 10°. | 15° to 20°. | 100°. | 200°. |
| I. | Gold, hard-drawn | 9351 | 8603 | .. | .. | .. |
| II. | .. annealed | .. | .. | 5585 | 5408 | 5482 |
| III. | Silver, hard-drawn | 7800 | 7411 | .. | .. | .. |
| IV. | .. annealed | .. | .. | 7140 | 7274 | 6374 |
| V. | Palladium, hard-drawn | 10659 | 10289 | .. | .. | .. |
| VI. | Platinum, hard-drawn | 16224 | 15647 | .. | .. | .. |
| VII. | .. annealed | .. | .. | 15518 | 14178 | 12964 |
| VIII. | Copper, hard-drawn | 13052 | 12200 | .. | .. | .. |
| IX. | .. annealed | .. | .. | 10519 | 9827 | 7862 |
| X. | Common iron wire, hard-drawn ... | 17743 | 18613 | .. | 19995 | .. |
| XI. | .. annealed | .. | .. | 20794 | 21877 | 17700 |
| XII. | (Common steel wire, tempered to blue.....) | 17690 | 18045 | .. | 18977 | .. |
| XIII. | English steel wire, annealed | .. | .. | 17278 | 21292 | 19278 |
| XIV. | Cast-steel, annealed | .. | .. | 19561 | 19014 | 17926 |
| XV. | Berlin brass, hard-drawn | 9782 | 9005 | .. | .. | .. |

NOTES ON THE PRECEDING TABLES.—By coefficient of elasticity is meant the weight in kilogrammes which would double the length of a rod of 1 square millimetre in sectional area, if such elastic elongation were physically possible (Wertheim). Hard-drawn means the state in which the metal is left after having been drawn out into wire; and annealed means the soft state induced by heating the hard-drawn wire to dull redness when the temperature of annealing is not particularly specified.

The copper operated upon in Nos. VIII. IX. of the second table is reported to have contained 0·38 % of silver and 0·80 % of iron, and must, therefore, be regarded as unusually impure.

The iron operated upon in Nos. X. XI. of the second table was the same as that in No. V. of the first.

The cast-steel operated upon in No. XIV. of the second table was the same as that in No. VI. of the first.

From the results presented in the last table it is inferred that the coefficient of elasticity of the metals, excepting iron and steel, decreases continuously as the temperature rises, from -15° C. to 200° C.; and that while in the case of iron and steel it increases from -15° C. to 100° C., it is not only less at 200° C. than at 100° C., but is sometimes even less than at the ordinary atmospheric temperature.

The conclusion which Styffe has drawn from his experiments on iron and steel is, that the coefficient or modulus of elasticity in both is increased by reduction of temperature and diminished by elevation of temperature; but that these variations never exceed 0·05 per cent. for a change of temperature of 1° C., and therefore such variations, at least for ordinary purposes, are of no special importance.*

Wertheim observed that in some of his experiments the action of cold was not always transient; for the increase in the specific gravity, and, consequently, in the elasticity, seems partially to remain after

* Styffe, *The Elasticity, etc., of Iron and Steel*, p. 112.

the metal had acquired its original temperature. Thus, a copper wire, of the specific gravity 8.902, at 7° C., was drawn out at the ordinary temperature. After it had passed through four holes in the draw-plate, its specific gravity was found to be 8.906; but when the drawing-out took place in a refrigerating mixture, so that the draw-plate and the wire were constantly kept at the temperature of -15° C., the specific gravity of the wire, after it had passed through the same number of holes, was 8.925, at 7° C. Mere refrigeration to -20° C. caused the specific gravity to rise from 8.906 to 8.927. A similar result was obtained with platinum. "It appears, then," writes Wertheim, "that low temperatures produce a permanent effect analogous to annealing, but in the opposite direction"; and he adds, by way of caution, that "it would be necessary to operate at much lower temperatures in order to be able to pronounce positively as to the generality of this fact."

Styffe asserts that by cooling to a very low temperature, no perceptible *permanent* influence is exerted on the position of the limit of elasticity in iron and steel.⁷

Moreover, Styffe states that, in the case of iron or steel if the modulus of elasticity is determined in a bar *immediately* after it has acquired a permanent elongation, say of about 0.5 per cent., and the bar is then set aside for several days, it will be found, on repeating the experiment, to have regained a portion of the elasticity which it had lost by stretching. The recovery of this elasticity is always greatly accelerated by heat; and, indeed, if the heat is raised to redness, the modulus may become as great as it was before stretching, and even greater, contrary to what Coulomb and Tredgold have stated. Not only stretching, but also forging, rolling, or any other violent mechanical treatment, if not performed at too high a temperature, diminishes the modulus of elasticity in steel and iron.⁸

While a wire or rod is subjected to the action of a pulling force, its length is increased and its sectional area diminished; but its volume, so far from remaining the same, is increased, or, in other words, its specific gravity is diminished. There is, however, considerable disagreement amongst mathematicians and physicists as to the relation which exists between the elongation and augmentation in volume. Poisson and some other mathematicians arrived at the conclusion that the elongation for the unit of length is double the diminution in section for the unit of sectional area, for which Jamin uses the single word *surface*; and experiments made by Cagniard de Latour confirmed that conclusion. On the other hand, Cauchy enunciated more general formulæ, which include, as a particular case, Poisson's solution, but which show that it is not essential, and that other relations between the actions in question may exist, to be decided only by experiment. Wertheim was led to conclude from his experiments on caoutchouc that the increase of

⁷ Styffe, *The Elasticity, etc., of Iron and Steel*, p. 109.

⁸ *Ibid.* pp. 67-69.

volume is sensibly equal, not to half, but to one-third, of that of the proportional elongation.*

It is elasticity that is concerned in the action of twisting, or torsion, of rods and wires. Suppose a pretty stout straight rod of metal, say of iron, to be placed horizontally, as in a lathe, with one end firmly fixed, and the other fitted into the axis of a wheel, having a cord round it fastened at one end. Now, let a weight be attached to the free end of the cord, and the bar will be twisted, or undergo torsion, in a certain degree, the angle of which may easily be measured by an obvious arrangement, namely, such as graduating the circumference of one face of the wheel into 360° , and fixing radially in front of that face an index needle. By experimenting in this manner, it has been proved that the angle of torsion is proportional, *directly* to the weight employed and to the length of the rod, and *inversely* to the square of the sectional area; and each substance has its own coefficient of torsion to be determined by experiment.

In the bending or flexure of rods elasticity is also the property concerned. Suppose a rod of metal, say of steel, rectangular in section, to be fixed horizontally at one end in a vice. Now, let a weight be applied to the other or free end, and the bar will be bent or flexed; and when the weight is taken off, the bar will again become straight, provided the limit of elasticity has not been exceeded. During the action of the weight, as the rod is curved, the upper surface is elongated and the lower one is contracted, the length of the axis remaining the same. Thus one half of the rod is lengthened, while the other half is shortened: so that in this case elongation and contraction concur equally in producing the effect of elasticity; and as one is exactly compensated by the other, there is no change in specific gravity. Hence, the neutral plane of the rod, or that which is neither contracted nor dilated, passes through its axis and divides the rod into two equal parts (Kupffer). In all rods, the flexure is *directly* proportional to the weight employed, and to the cube of the length; in cylindrical rods, it is *inversely* proportional to the fourth power of the radius, and in prismatic ones, *inversely* to the width or horizontal side of the rod, and to the cube of the thickness or vertical side of the rod; and each substance has a co-efficient of flexure to be determined by experiment.

When the rod has been deflected from its position of equilibrium, it tends to revert to it by virtue of a force, which is at each moment proportional to the distance of each of its points from their position of equilibrium; and the oscillations which the rod describes, in order to regain its position of equilibrium, are isochronous, whatever may be their amplitude. It is easy to demonstrate this isochronism; for the oscillations, being very rapid, produce a sound of which the pitch varies with the number of the oscillations per second, and this pitch is constant when the amplitude of the oscillations changes. The

* See Jamin's Cours de Physique, 1858, i. 139, for further information on this part of the subject.

fact of the invariability of the pitch of the sound is at once a proof and a consequence of the law preceding, namely, of the proportionality of the force to the flexure (Jamin). But, according to Kupffer, the torsion oscillations (*les oscillations tournantes*) of elastic wires are not rigorously isochronous, and the deviation from isochronism is very different for wires of different metals—an effect which he conceives to be due to a new property of metals in intimate connection with their malleability.

With regard to the methods of ascertaining the coefficient or modulus of elasticity, Styffe makes the following observations:—

“As Wertheim used in his experiments wire, which, according to his statements, had a diameter of only from 0·1 to 0·5 line, he was but little exposed to error in respect of its curvature; but, on the other hand, he was unable to accurately measure its sectional area, except by calculating the mean area from the specific gravity. As the wires were only about 2·5 ft. long between the points where the elastic elongations were measured, and as these measurements were obtained by means of a cathetometer, the values of the modulus of elasticity calculated by him from his experiments on traction not unfrequently varied for the same iron and steel wire to the extent of 10 per cent. and upwards.

“The modulus of elasticity may certainly be more accurately obtained by flexion than by traction, as the amount of deflection may be considerably greater, and therefore more accurately measured, than the elastic elongation by tension. But supposing that the value of the modulus of elasticity thus obtained is an exact measure of the elastic force on stretching, it is assumed that this force is equal to the elastic force on compression, whilst, according to Hodgkinson, the latter for iron is about $\frac{1}{2}$ of the former; and also that by different strains in different directions, and by the change of form in the sectional area which occurs on flexure, other forces are developed, or the conditions are otherwise so changed that the calculations from the common formula become, as some authors affirm, uncertain. Wertheim in one case obtained the modulus of elasticity for steel wire more than 20 per cent. higher by means of transverse vibration than by traction. Kupffer's determinations of the modulus of elasticity by flexion and transverse vibrations agree very well *among themselves*; but, although the amount of deflection was determined in his experiments with great accuracy by affixing mirrors to the ends of the sample-bars and measuring the inclination which these mirrors assumed in different positions of the bars, yet his results *may* be affected by errors amounting at least to $1\frac{1}{2}$ per cent., as his bars had a thickness of only 0·8 to 1·7 line. The third power of this thickness enters into the formula for calculating the modulus of elasticity by flexion, and therefore an error in measurement of 0·00058 inch, which for the thinner bars is more than $\frac{1}{2}$ per cent. of their thickness, causes an error of upwards of $1\frac{1}{2}$ per cent. in the modulus. That an error of measurement of this magnitude has been committed, may be seen by comparing the thickness measured with that calculated from the specific gravity.”¹

¹ Styffe, *The Elasticity, etc., of Iron and Steel*, p. 61.

It will be borne in mind that if the limit of elasticity is once exceeded, there will be permanent alteration of form; and to an action of this kind may be ascribed the elongation of a wire when it is passed through a draw-plate, the impression which a metallic disc receives in the coining-press, the lamination of metals by rolling, the hammering out of metals, and in general all the changes in form or distortions which are produced by any of the operations above named, without effecting actual rupture. A rod may be twisted at a small angle without permanently altering the form, but when it is twisted beyond a certain angle, it will remain twisted after the torsion force has ceased to act. So also a spring may be bent to a certain degree, and recover its original form after the cessation of the bending force, but beyond that degree it will remain distorted after the removal of that force. The duration of the force is an element of great importance in considering elasticity: for springs, which have only been subjected to the action of a force, operating sensibly within the *accepted* limit of elasticity, become permanently distorted and lose their power, after the lapse of time; and beams or girders exposed to like conditions become gradually and permanently bent.

MALLEABILITY.

MALLEABILITY IS THE PROPERTY OF PERMANENTLY EXTENDING WITHOUT RUPTURE BY PRESSURE (AS IN ROLLING), OR BY IMPACT (AS IN HAMMERING).—It is opposed to brittleness, which is the property of more or less readily breaking under compression, whether gradual or sudden; gold and copper are malleable, antimony and bismuth brittle.

Malleability may be much affected by temperature: thus ordinary copper is malleable when cold as well as when heated below a certain degree; but beyond that degree it becomes so brittle, that it may be readily reduced to powder. Zinc in ingot is only malleable at about 150° C. Iron continues malleable even when near its point of fusion.

Malleability is also affected by molecular condition. A metal may lose its malleability by being hammered or rolled, and can only regain it by being heated to a certain point. The method of restoring malleability by means of heat is constantly employed in the arts, and is termed *annealing*. In rolling a metal—that is, in subjecting it to pressure between strong revolving metallic cylinders, technically termed “rolls,” of which the axes are parallel, usually horizontal, and in the same vertical plane—annealing from time to time is, in most cases, necessary; otherwise, not only would the process proceed with difficulty on account of increasing hardness, but the metal would crack, especially at the edges. With some metals, for example copper, it is immaterial whether the cooling after annealing takes place slowly or rapidly; but with others it is very material: thus, bronze, containing about 20 per cent. of tin,² is rendered most malle-

² Riche, *Ann. de Chim. et de Phys.* s. 4, 1873, xxx. 417.

able by rapid cooling, while steel can only be rendered malleable by slow cooling. The malleability of a metal may be affected by the character of its crystalline structure. Thus, when once the crystalline structure of an ingot of zinc is, as it were, broken down by the process of rolling at the proper temperature, the sheet of metal obtained may be much further reduced in thickness by rolling it while cold. The hardness which it thereby acquires may be removed by annealing at a low temperature; but if the sheet is heated to a degree bordering on its point of fusion, it becomes extremely brittle, whether cooled slowly or rapidly. The sheet before being heated to this point emits no sensible crackling sound by being bent backwards and forwards; but, after having been thus heated, it emits a very audible crackling sound, due, doubtless, to the tearing asunder of the crystals, which have been reproduced by the exposure of the metal to a temperature even below its point of fusion.

Some alloys or mixtures of metals with each other undergo molecular changes in process of time, at ordinary atmospheric temperatures, which affect their malleability. Some kinds of brass wire become very brittle, especially when kept in a state of tension. An alloy of tin and lead, which is used in pattern-casting for brass-foundry work, and which at first is comparatively hard, becomes after a time so soft as to be no longer fit for use.

DUCTILITY.

DUCTILITY IS THE PROPERTY OF PERMANENTLY EXTENDING BY TRACTION (AS IN WIRE DRAWING).—Although all ductile metals are necessarily malleable, yet they are *not necessarily ductile in the exact ratio of their malleability*. Thus, iron is very ductile, and may be drawn out into very fine wire; but it cannot, like some other less ductile metals, be hammered or rolled out into extremely thin sheets.

The following table of metals, arranged in the order of their malleability and ductility,³ is usually found in books; but since the more recent and exact examination of some metals by Deville and others, it may have to be considerably modified. Nickel and cobalt, for example, have been found to possess much greater malleability and tenacity than was formerly believed.

| Malleability. | Ductility. |
|---------------|--------------|
| 1. Gold. | 1. Gold. |
| 2. Silver. | 2. Silver. |
| 3. Copper. | 3. Platinum. |
| 4. Tin. | 4. Iron. |
| 5. Platinum. | 5. Nickel. |
| 6. Lead. | 6. Copper. |
| 7. Zinc. | 7. Zinc. |
| 8. Iron. | 8. Tin. |
| 9. Nickel. | 9. Lead. |

Wertheim conceived that a *perfectly homogeneous* wire of ductile

³ Regnault, Cours élémentaire de Chimie, ii. 26. This table is nearly the same as that of Thénard, Traité de Chimie, 6^{ème} éd. ii. 12.

metal should either be capable of being drawn out to infinity, or, if not, when the distance between the particles (*molécules*) is such that on separating them further from each other, the resultant of the molecular forces becomes less than the force employed, there ought not to be rupture in a single place, but the entire wire should fall to powder.⁴ It is, however, a question whether, in this purely hypothetical case, the element of time would not come into play and determine rupture in that part of the wire, say the end, to be first acted upon by the final rupturing force; for it is impossible that all the particles of the wire should, speaking with mathematical precision, be *simultaneously* affected by that force.

FLOW OF METALS.

When a malleable metallic mass is extended by compression, as in rolling,—by stamping, as in the manufacture of such objects as curtain-bands, jelly-moulds, etc.,—or by squeezing through apertures, as in the usual process of manufacturing lead pipes,—a veritable flow of the particles of the mass occurs, analogous in all respects to the flow of liquids. This subject has been systematically investigated by Tresca, of the Conservatoire des Arts et Métiers in Paris, and the record of his results may be consulted with advantage.⁵ The general law which he deduced from his experiments is, that, “when pressure is exerted upon the surface of any material, it is transmitted in the interior of the mass from particle to particle, and tends to produce a flow in the direction where the resistance is least.” By operating upon superposed discs of lead, he was able to trace what occurs by observing the structure induced in the mass by this treatment, which became manifest on cutting it in transverse and longitudinal directions. In the case of iron, the structure was revealed by the action of a dilute aqueous solution of corrosive sublimate, on the polished and perfectly cleaned surface of the metal. In rolling, the metal is prevented from extending laterally by the frictional resistance of the rolls. In rolling a slab of lead, the mass of which has the same, or nearly the same, temperature throughout, the end which has passed through is concave; whereas in rolling a slab of iron, strongly heated, it is convex, because the metal in the interior, being much hotter and therefore softer than that towards the exterior, yields more easily to pressure than the latter. In squeezing a solid cylinder of lead through a rigid aperture of less diameter than its own, the ends become concave and funnel-shaped, because the metal in this case, as in that of the rolled slab, being uniformly soft throughout, the effect of compression is greatest where the resistance to extension is least. The structure caused by rolling and hammering will be considered at length in the second volume of this work, on Iron and Steel.

⁴ Ann. de Chim. et de Phys. s. 3, 1844, xii. 441. | Mechanical Engineers held at Paris in 1867, Proceedings of the Institution of

⁵ See paper read before the Meeting of | Mechanical Engineers, 1867, pp. 114 *et seq.*

TENACITY, OR TENSILE STRENGTH.

TENACITY IS THE PROPERTY OF RESISTING RUPTURE BY TRACTION.—It is proportionate to the weight which the wire of a given metal is capable of sustaining without breaking. To determine the tenacity of different metals, wires of *exactly the same diameter*, or which have passed through the same *draw-plate*, have been prepared; and the utmost weight, which each wire is capable of suspending without breaking, has been exactly determined. This weight is *the measure of the resistance to rupture*, or *the tenacity*. But the method adopted in practice of ascertaining tensile strength is somewhat different; it is as follows:—Cylinders of the metal are prepared, which are much greater in diameter at the ends than in the central portion. When the nature of the metal permits, they should be turned in a lathe. One end of the cylinder is firmly fixed with the axis vertical, while the other is attached to apparatus for producing traction either by a system of weighted levers or by hydraulic power, the force in both cases being capable of accurate measurement. The rupturing force is put into action, and gradually increased until the cylinder breaks. The breaking weight being thus found, and the diameter of the weakest part of the cylinder before the experiment known, it is easy to calculate the rupturing force that would be required for 1 square inch of cross-sectional area, since the force required is inversely as the sectional area; and in this country this is always done by engineers, in order that results may be immediately compared with each other. This force, or tensile strength, may either be expressed in statute tons or in avoirdupois pounds. Annexed are woodcuts, figs. 1 and 2, showing cylinders of steel and iron of the exact dimensions used at the Arsenal at Woolwich for this purpose. Tenacity is estimated in France by the weight in kilogrammes which is required to break a wire of 1 millimetre square in sectional area. It is desirable in every experiment to note the diameter of the fractured part, and the degree of elongation which the metal undergoes before breaking. It may be remarked that, generally, elongation increases more rapidly, at least in the case of iron and steel, as the traction force approaches that which suffices to cause



Fig. 1. Steel.



Fig. 2. Iron.

As it is required to ascertain the tensile strength of the metal in the same state as that in which it is to be used, and as it is subjected before use to certain processes, termed tempering and hardening, the bars are similarly treated before they are placed in the testing-machine. When thus treated, they have the dimensions indicated by the inner dotted lines, but are afterwards turned in a lathe to the dimensions indicated by the shading in the woodcuts.

rupture; and that the degree of elongation on rupture depends to a great extent on the rapidity with which rupture is effected. The diminution of the area at the place of rupture affords a pretty sure indication of the ductility of the metal; but the degree of diminution may be also greatly dependent on the homogeneity of the metal, its freedom from flaws, and the manner in which it has been treated during the experiment (Styffe).

The temperature should also be observed, as well as the time required for effecting rupture. Time is a very important element in relation to tensile strength. Thus a metal which possesses great tensile strength when tested by the gradual and slow application of the force of traction, may prove to be comparatively weak when this force is very suddenly applied; indeed, much weaker than another metal of far less tensile strength, as determined in the usual way. This has been well exemplified in the trial at Shoeburyness of armour-plates of steel or steely iron, and soft wrought-iron. These varieties of iron differ much from each other in their power of what may be termed *rapid extensibility* when subjected to the action of a rupturing force of high velocity, such as that of cannon balls moving at the rate of 1200 or 1600 feet in a second. Under these conditions steel or steely iron is shattered into fragments, while soft wrought-iron may show a sensible degree of ductility or extensibility before cracking or rupturing.

It will be perceived that in determining the tenacity or tensile strength of a metal there is the same difficulty as in the investigation concerning its elasticity. The force required to produce rupture varies with the conditions of the experiment; for, as soon as the limit of elasticity is surpassed, the wire or rod gradually elongates, its molecules are at first displaced and afterwards suddenly separate; so that under a medium weight, long continued, a rod may be broken which would resist a much more powerful force acting during a shorter period. This gradual diminution in tenacity is a fact which ought to be taken into account in constructing buildings (Jamin).

Tenacity is much affected by molecular condition. The presence of foreign matters, even in minute proportion, may lessen or increase the tenacity of a metal. This circumstance, and that of difference of molecular condition consequent on previous treatment, mechanical or other, will explain the variations which *apparently* the same metal may present in respect to tenacity.

As might have been anticipated, variation in temperature, even within comparatively narrow limits, is found to occasion considerable variations in the tenacity of metals. Baudrimont has published the following results on this subject, obtained by operating upon wires.*

* Ann. de Chim. et de Phys. s. 3, 1850, xxx. 304 et seq.

TENACITY OF THE PRINCIPAL MALLEABLE METALS AT THE TEMPERATURES OF 0°, 100°, AND 200° C., AS FOUND BY EXPERIMENT WITH THE TENACITY CALCULATED FOR 1 SQUARE MILLIMETRE (0·00155 SQUARE INCH) OF SECTIONAL AREA.

| Metals. | Diameter of the Wire at 16° C. | Tenacity | | | Tenacity calculated for 1 sq. mm. of Sectional Area | | |
|-----------------|--------------------------------|----------|----------|----------|---|----------|----------|
| | | at 0°. | at 100°. | at 200°. | at 0°. | at 100°. | at 200°. |
| | millimetre. | grms. | grms. | grms. | grms. | grms. | grms. |
| Gold | 0·41250 | 2459 | 2035 | 1722 | 18400 | 15224 | 12878 |
| Platinum | 0·41000 | 2987 | 2546 | 2281 | 22625 | 19284 | 17277 |
| Copper | 0·48000 | 4542 | 3958 | 3296 | 25100 | 21873 | 18215 |
| Silver | 0·39825 | 3528 | 2898 | 2314 | 28324 | 23266 | 18577 |
| Palladium | 0·39750 | 4527 | 4031 | 3360 | 36481 | 32484 | 27077 |
| Iron | 0·17500 | 4940 | 4611 | 5057 | 205405 | 191725 | 210270 |

The following results are deducible from this table, but they differ from the deductions of Baudrimont, which appear to be incorrect:—

1. The tenacity of metals varies with the temperature.
2. It decreases generally, but not without exceptions, when the temperature increases.
3. With gold and platinum the ratio of diminution is less between 100° C. and 200° C. than between 0° C. and 100° C.
4. With silver, copper, and palladium, the reverse is the case.
5. Iron presents a special and very remarkable case: at 100° C. its tenacity is less than at 0° C., but at 200° C. it is greater than at 0° C.

Wertheim directed attention to the high number given in this table for the tenacity of iron, which notably exceeded what he had found, and remarks that, "in general, as is known, determinations of cohesion or tenacity are not susceptible of great accuracy, especially when wires of such a small diameter are the subject of experiment."⁷ To this Baudrimont replied that he had accurately stated the results of his experiments upon the iron wire, and that, as iron is known to be very variable in quality, it is not reasonable to expect that it should always have the same tenacity.⁸ It is well known that when iron wire is drawn out finer, its tenacity per unit of sectional area is considerably increased; so that the number found for tenacity by operating upon iron wires, especially if thin, cannot be applied to rods or bars of the *same* metal. The tenacity of metals is greater when they have been hardened by mechanical treatment, such as wire-drawing, rolling, hammering, stamping, and coining, than in the annealed state.

The difference between the force which marks the limit of elasticity and that which causes rupture varies for different metals; and the greater that difference is the greater will be the ductility of the metal. But ductility cannot be measured by comparing the limit of elasticity, found by any of the methods in use, with the tenacity; because, in passing the metal through a draw-plate, it is

⁷ Ann. de Chim. et de Phys. s. 3, 1850, xxx. 507.

⁸ Ibid. xxxi. 509.

subjected to two kinds of action, one of traction and the other of transverse compression, and the effect is more complex than that which has been considered under the head of elasticity (Jamin). The proof of the main propositions in this and the preceding paragraph is shown in the following table.

TABLE SHOWING THE EFFECT OF HARDENING AND ANNEALING UPON THE TENACITY OF METALS AND THE INEQUALITY BETWEEN THE WEIGHT CAUSING RUPTURE AND THAT MARKING THE LIMIT OF ELASTICITY.*

| Metals. | Weight marking the Limit of Elasticity. | Coefficient of Rupture or Tenacity. |
|------------|---|---|
| | In kilogr. per sq. mm. of Sectional Area. | |
| Lead | { Hard-drawn 0·25 | 2·50 |
| | { Annealed 0·20 | 1·80 |
| Tin | { Hard-drawn 0·40 | 2·45 |
| | { Annealed 0·20 | 1·70 |
| Gold | { Hard-drawn 13·50 | 27·00 |
| | { Annealed 3·00 | 10·08 |
| Silver ... | { Hard-drawn 11·00 | 29·00 |
| | { Annealed 2·50 | 16·02 |
| Copper... | { Hard-drawn 12·00 | 40·30 |
| | { Annealed 3·00 | 30·54 |
| Platinum | { Hard-drawn 26·00 | 34·10 |
| | { Annealed 14·50 | 23·50 |
| Iron | { Hard-drawn 32·50 | 61·10 |
| | { Annealed 5·00 | 46·88 |
| Cast-steel | { Hard-drawn 55·60 | 80·00 |
| | { Annealed 5·00 | 65·70 |

The results recorded in the preceding table should be carefully noted. Any mechanical or other treatment of a metal which induces hardening, such as cold-hammering, cold-rolling, wire-drawing, stamping, or coining, tends to increase its tenacity and the limit of its elasticity, but to diminish its ductility. It has also been found that by hardening steel and iron by heating and sudden cooling the limit of elasticity is raised, whereas ductility is lessened in both by this operation.¹

Seguin has obtained the following results of the effect of increase of temperature upon tenacity, that of each metal being taken as 100 at 10° C.²

| Temperature. | Tenacity at given Temperature. | | |
|--------------|--------------------------------|---------|--------|
| | Iron. | Copper. | Brass. |
| 10° C. | 100 | 100 | 100 |
| 370° | 90·5 | 86·6 | 19·6 |
| 500° | 58·7 | .. | .. |

* From Jamin's Cours de Physique, i. 135, founded on Wertheim's experiments. See table, Ann. de Chim. et de Phys. s. 3, 1844, xii. 438.

¹ Styffe, The Elasticity, etc., of Iron and Steel, p. 72.

² Comptes rendus, 1855, xl. 8.

According to Styffe, the tensile strength of iron and steel is not diminished by cold, and even at the lowest temperature that ever occurs in Sweden, it is at least as great as at the temperature of 14.5°C . (58.1°Fahr.); and while at temperatures between 100°C . (212°Fahr.) and 200°C . (392°Fahr.) the tenacity of steel is nearly the same as at the ordinary temperature, in soft iron it is always greater.³ But it has been demonstrated by C. Sandberg that iron rails become more fragile in severe cold when subjected to *concussive* action, though the tensile strength of iron, when determined by a slowly exerted rupturing force, may be greater at very low than at ordinary temperatures.

ON THE ACOUSTIC METHOD OF DETERMINING TENACITY.

The tenacity of a metal in the form of wire may be found by gradually straining it in the direction of its length until it breaks, and observing the musical note which it emits when thrown into vibration just before the moment of rupture. By way of illustration, the following results obtained by my friend, Dr. William Pole, in conjunction with Messrs. Broadwood and Sons, pianoforte manufacturers, are here introduced. These results are given nearly in Dr. Pole's own words.

I. A sample of steel wire, called No. 14 of the pianoforte gauge, and used in the treble part of the instrument, was supported on two bridges, and broken by direct tension. The vibrating part of the string was $23\frac{1}{2}$ inches long, and just before it broke, it sounded about the note G on the second line of the treble stave. To ascertain the diameter of the string, a yard of it (measured when in tension) was found to weigh exactly 60 grains. Now, taking its sp. gr. as 7.85, a cubic inch would weigh 1990 grains, and its cross-sectional area would be $\frac{1}{11\frac{1}{8}}$ of a square inch. The string broke under a longitudinal strain of 225 lbs., which is equal to a tenacity of 118 tons per square inch of cross-sectional area. The breaking force was measured directly by a spring balance attached to one end of the wire; but, as a check, it was also calculated from the note sounded, according to the laws of acoustics, thus:—if V be the number of single vibrations per second, made by a string whose length in inches = l , and weight in lbs. = w , then the tension in lbs. (= T) will be

$$T = \frac{V^2 lw}{386.156}$$

Now the note G above referred to corresponds to about 800 single vibrations per second; the weight of the string is 39.2 grains, and $l = 23.5$ inches. Hence the tenacity = 218 lbs., which approximates pretty closely to the number 225 lbs., found by direct observation.

II. In this experiment a steel wire of the size called No. 17, used

³ Styffe, *The Elasticity, etc., of Iron and Steel*, p. 111.

in the middle of the piano, and weighing 76 grains per yard, was operated upon. The same length of wire gave the same note as before, and broke under a strain of 284 lbs., which is equal to a tenacity of 120 tons per square inch.

III. In this experiment a steel wire, called No. 20, used in the lower part of the piano, and weighing 103 grains per yard, was tried. The same length of wire gave the note F, and broke under a strain of 352 lbs., which is equal to a tenacity of 110 tons per square inch.

TOUGHNESS.

This term, which is nearly allied to tenacity, is constantly in use amongst practical metallurgists to denote the property of resisting extension or fracture by tearing or bending. Thus a piece of copper is said to be tough in proportion to its capability of being bent backwards and forwards without breaking; and one of the varieties of copper known in commerce is called *tough-cake*. The following illustration of the term toughness, as applied to steel, was given by Dr. Young:⁴—"Steel, whether perfectly hard or of the softest temper, resists flexure with equal force when the deviations from the natural state are small; but at a certain point, the steel, if soft, begins to undergo an alteration of form; at another point it breaks if much hardened; but when the hardness is moderate, it is capable of a much greater curvature, without either permanent alteration or fracture; and this quality, which is valuable for the purposes of springs, is called *toughness*, and is opposed to *rigidity* and *brittleness* on the one side, and to *ductility* on the other."

G. Bischof, Junior, has invented a machine designated a "Metallometer," for the purpose of ascertaining what he terms the "quality" of malleable metals and alloys. Small rolled and annealed strips of the metal to be tested are prepared, so as to be identical, as far as practicable, in dimensions and other respects; and these strips are bent backwards and forwards to the same extent in each direction until they break. The "quality" of the metal is estimated by the number of times which it suffers flexion without breaking. Toughness would seem to be the proper appellation for the quality in question.⁵

SOFTNESS.

This term is used to denote the property of a metallic mass of *easily* yielding to compression without fracture, and not returning to its original form after the removal of the compressing force; and in

⁴ Nat. Phil. i. 142.

⁵ It is stated that the metallometer has been patented in England, France, Belgium, Prussia, Russia, Austria, and America. A detailed description of the machine will be found in a pamphlet

published in English at Bonn in 1870, entitled "A New Method of and Apparatus for Testing the Quality of the Malleable Metals and Alloys, by Gustav Bischof, Jun."

this sense it is opposed to elasticity. It is the property essentially concerned in the striking of medals. It is also used by metallurgists in the sense of being easily *sectile*. Strictly speaking, the term *soft* must always be comparative; but in metallurgical language, while it is frequently used comparatively, it has yet a more technical meaning. Thus metals are practically divided into *soft* and *hard*; lead and tin are examples of the former, copper and iron of the latter. But varieties of the same *soft* metal are constantly compared with each other in respect to softness; thus, commercial varieties of lead are divided into *soft* and *hard*. The *hard* metals are also similarly compared with each other; steel is said to be *soft* or *hard*, according to the condition induced by previous special treatment.

Temperature must obviously have the greatest influence in determining the softness of a metal. At the ordinary temperature, sodium amongst the rarer metals, and lead amongst those in common use, are examples of the softest metals; while the *least soft*, or *hardest* metal by far, is the native osmium-iridium alloy, which is harder than the hardest steel. Chromium is also extremely hard, indeed sufficiently so to *cut* glass. What the *actual* effect of the *total deprivation* of heat might be in determining *hardness*—whether, for example, lead would then become as hard as iron—we have no means of knowing. But we do know positively the effect of heat in determining softness.

CONDUCTION OF HEAT AND ELECTRICITY.

One of the most prominent characters of the metals is, certainly, their superior power of conducting heat and electricity. The results on the conductivity of metals for heat, which have been obtained by Wiedemann and Franz,⁶ are stated numerically in the following table, the conductivity of silver being assumed to be 100:—

| | At 12° C. | | At 12° C. |
|--------------|-----------|------------------------|-----------|
| Silver | 100 | Steel | 11·6 |
| Copper | 73·6 | Lead | 8·5 |
| Gold | 53·2 | Platinum | 8·4 |
| Brass | 23·6 | German silver | 6·3 |
| Tin | 14·5 | Rose's fusible metal.. | 2·8 |
| Iron | 11·9 | Bismuth | 1·8 |

So long ago as 1833,⁷ Professor J. D. Forbes, of Edinburgh, was led to infer that “the order of conducting power of the metals for *heat* and for *electricity* is the same”; and that this inference is very probably correct will appear from the following table of the conductivity of various metals for electricity:—

⁶ Poggendorff's *Annalen*, 1853, lxxix. 497. An account of these researches has been given by Professor Tyndall in the *Philosophical Magazine*, s. 4, 1854, vii. 33.

⁷ *Phil. Mag.* s. 3, 1834, iv. 27.

| | Ries. | Lenz. | Arndtsen.* | Matthiessen.* | |
|------------------|-----------|----------|------------|---------------|-----------|
| | | | | Hard-drawn. | Annealed. |
| | At 15° C. | At 0° C. | At 0° C. | At 0° C. | |
| Silver | 100 | 100 | 100* | 100* | 110 |
| Copper..... | 66·7 | 73·3 | 98·7 | 99·5* | 102 |
| Gold | 59·0 | 58·5 | .. | 78* | 80 |
| Brass | 18·4 | 21·5 | 25·4 | .. | .. |
| Tin | 10·0 | 22·6 | .. | At 21° C. | 11·4* |
| Iron..... | 12·0 | 18·0 | 14·8 | .. | .. |
| Steel | .. | .. | .. | At 20°·4 C. | 14·4 |
| Lead | 7·0 | 10·7 | 9·1 | At 17°·3 C. | 7·8* |
| Platinum | 10·5 | 10·8 | 14·5 | At 20°·7 C. | 10·5 |
| German silver... | 5·9 | .. | 18·7 | At 18°·7 C. | 7·7 |
| Bismuth | .. | 1·9 | .. | At 18°·8 C. | 1·2* |

Those marked * are stated by the authors to have been pure.

Whatever the quality may be upon which calorific conduction depends, it is, as Professor Tyndall remarks, "exceedingly probable that the same quality influences in a similar manner the transmission of electricity; for, the divergences of the numbers expressing the conductivity for heat from those expressing the conductivity for electricity, are not greater than the divergences of the latter alone, exhibited by the results of the different observers."

In the case of iron, Professor Forbes states that he has found the conductivity for heat to vary with the temperature; or, in his own words, that "the flux of heat through the solid is not in a simple direct proportion to the difference of temperature of two contiguous thin slices, but varies in a less rapid proportion; or, the conductivity diminishes as the temperature increases."¹ When the statement was announced, he had only experimented upon iron.

The conductivity of metals for electricity has been found to vary with the temperature. The following experiments on this subject have been made by Lenz² and Arndtsen: the conductivity of each metal is estimated as 100, at 0° C.

| | Lenz. | | | Arndtsen. | |
|---------------|----------|------------|------------|------------|------------|
| | At 0° C. | At 100° C. | At 200° C. | At 100° C. | At 200° C. |
| Silver | 100 | 74·5 | 56·6* | 74·5 | 59·4* |
| Copper | 100 | 77·7 | 61·0 | 73·0 | 57·5 |
| Gold | 100 | 84·9 | 73·7 | .. | .. |
| Tin..... | 100 | 71·8 | 53·4 | .. | .. |
| Brass | 100 | 87·6 | 78·0 | 87·3 | 79·9 |
| Iron..... | 100 | 67·7 | 46·2 | 67·2 | 49·1 |
| Lead | 100 | 71·4 | 52·3 | 72·6 | 57·0 |
| Platinum..... | 100 | 81·0 | 68·0 | 75·3 | 60·4 |

Those marked * are stated by the authors to have been pure.

¹ Poggendorff's Annalen, 1858, civ. 1.

² Phil. Trans. 1858, cxlviii. 383.

³ Brit. Ass. Rep. 1852, p. 261.

* Mém. de l'Acad. impér. des Sci. de St.-Petersbourg, s. 6, 1838, i. 439.

It has been demonstrated that the electric conductivity of many metals is affected in a remarkable degree by certain foreign matters, when present even in very small proportion. This is a matter of great practical importance to telegraphic engineers; and in a subsequent part of this volume, under the head of "The Electric Conductivity of Copper," a record of the results of numerous experiments upon it will be found.

It is probable that the conductivity of all metals for heat and electricity is affected by molecular condition. According to Peltier,³ copper wire conducts electricity better after having been heated to redness, and soft steel better than the same steel hardened; and similar results by Matthiessen are given in the last table but one. The molecular condition of metals is, as has been stated, changed, not only by various mechanical processes, but especially by the rate of cooling after fusion, or by exposure to heat. Hence, in researches upon the conductivity of metals, it is important to note, not only the degree of purity and temperature of the specimens operated upon, but also the precise treatment which they have received; for, otherwise, satisfactory comparisons cannot be made between the results of different observers.

CAPACITY FOR HEAT.

Equal weights of different metals require different amounts of heat to raise them from the same to a higher given temperature. The amount of heat necessary to raise 1 part by weight of water from 0° C. to 1° C. being 1, the amounts of heat required respectively to raise the same weight of the following metals from 0° C. to 1° C. will be as follow :—⁴

| | | | |
|----------------|--------|----------------|--------|
| Iron | 0·1138 | Cadmium | 0·0567 |
| Nickel | 0·1086 | Tin..... | 0·0562 |
| Cobalt | 0·1070 | Antimony..... | 0·0508 |
| Zinc | 0·0955 | Platinum | 0·0324 |
| Copper | 0·0952 | Gold | 0·0324 |
| Palladium..... | 0·0593 | Lead | 0·0314 |
| Silver..... | 0·0570 | Bismuth | 0·0308 |

EXPANSION BY HEAT.

Metals expand when heated, and, within certain limits, generally in a degree proportionate to the temperature; but there are metals which, on crystallizing after fusion, expand at the moment of solidification, just as in the analogous case of the congelation of water. This subject is of great practical importance. The degree of expansion for each metal will be stated in due course in this work.

OPACITY.

OPACITY IS THE PROPERTY OF INTERCEPTING THE PASSAGE OF LIGHT.—All metals, in the solid state, may be regarded as perfectly opaque, except in certain cases of extreme thinness. Thus a greenish light

³ Berzelius, *Traité de Chimie*, Paris, 1846, ii. 6.

⁴ Regnault, *Cours élémentaire*, ii. 28.

traverses gold-leaf, which, it is stated, sometimes does not exceed $\frac{1}{1000}$ of an inch in thickness. As the light thus transmitted is polarized, it is certain that it passes through the substance of the metal, and not through minute holes, which might be supposed to be produced in the process of gold-beating. Silver-leaf, on the contrary, is perfectly opaque. But the light which traverses leaf prepared from gold alloyed with a certain proportion of silver is purplish instead of greenish.⁵ As some of the metals are brittle, and others differ very widely from each other in degree of malleability, and as only gold can be beaten out into leaves so extremely thin as to transmit light, it is obvious that no proper comparison can be instituted between them with respect to opacity. However, some metals have been deposited from solution upon glass in the form of continuous films of extraordinary tenuity, which possess brilliant metallic lustre and transmit light. Platinum, for example, may be thus deposited, when it transmits brownish light; and glass, coated with a film of silver for Steinheil's mirror, transmits bluish-purple light.

LUSTRE.

The characteristic lustre, termed *metallic*, is due to the manner in which light is reflected from the polished surfaces of metals. It is variable with the nature of the metal and the degree of polish. Metals in a state of fine division, like copper rapidly precipitated from solution by iron, do not present their characteristic lustre, but immediately acquire it when the powder is rubbed with a burnisher. Metallic lustre is not restricted to metals in their metallic state: thus, nothing can be more characteristic of such lustre than that of a variety of native crystallized sesquioxide of iron in brilliant plates (*specular iron-ore*), of some varieties of native crystallized sulphide of lead (*galena*), bisulphide of iron (*iron-pyrites*), and arsenide of cobalt (*smaltine*). Graphite, crystallized silicon, selenium solidified after fusion, and iodine, may be cited as examples of so-called non-metallic elements which possess metallic lustre.⁶

COLOUR.

It is difficult to frame any classification of the metals founded upon colour which shall in all respects be quite satisfactory; but the following may probably be adopted as at least convenient and practical:⁷—

WHITE.—SILVER-WHITE.—Silver must be classed alone in this division.

WHITE, INCLINING TO SILVER-WHITE.—Tin, cadmium, or mercury, may be taken as examples.

WHITE, INCLINING TO BLUE.—Antimony, zinc, lead.

YELLOWISH-WHITE.—Bismuth.

⁵ This subject of the transmission of light through gold in a state of fine division has been investigated by Faraday, whose results are recorded in the Philosophical Transactions, 1857.

⁶ On the subject of metallic reflexion

see Jamin's Cours de Physique, 1866, iii. 687, 691, and Ann. de Chim. et de Phys. s. 3, 1847, xix. 296 *et seq.*

⁷ Thénard, Traité de Chimie, 6^{ème} éd. ii. 8.

GREY.—The varieties of pig-iron, known as *grey-pig*, furnish characteristic examples of this colour.

YELLOW.—Gold, and certain alloys of copper and zinc, copper and tin, and copper and aluminium.

RED.—Copper, which varies in colour from purplish-red to orange. The peculiar copper-coloured compound of titanium, which is found in the hearths of blast-furnaces, and which at one time was mistaken for copper, is the only other metallic substance which has the colour and lustre of copper.

VIOLET.—The alloy of copper and antimony, which the alchemists called the *Regulus of Venus*, has a characteristic and beautiful violet colour.

When light is reflected several times between two more or less parallel plates of the same polished metal intense colours are produced: thus, with copper and gold the colour is purple, with silver it is golden-yellow, with steel and zinc it is blue, and with speculum-metal (an alloy of copper and tin) it is reddish. The effect may be observed by slightly opening a silver or gold watch-case and looking into the space between the two opposite surfaces.⁸

OCCLUSION OF GASES.*

This comparatively novel subject has been investigated by the late Mr. Graham, who was assisted in his experiments by Mr. W. C. Roberts, formerly a student of the Royal School of Mines, and now Chemist to the Mint; and I am indebted to Mr. Roberts for the following account of Graham's results, which has been compiled expressly for this volume.

MM. Henri Sainte-Claire Deville and Troost discovered that hydrogen would pass through a plate of platinum prepared from the fused metal, or through iron, at a red-heat. And it was well-known that molten silver had the power of absorbing many times its own volume of oxygen. In Deville's experiments on the passage of gases through tubes of iron and platinum, heated to redness, a new kind of porosity was imagined, more minute than that of graphite and earthenware, an intermolecular porosity due entirely to dilatation.¹

The experiments, of which the following is a brief account, were instituted by Graham in order to ascertain whether the passage of a

* For further information see the article on the colour of metals in Jamin's *Cours de Physique*, 1866, iii. 693.

⁸ References to papers by the late Thomas Graham, F.R.S. :—

On the Absorption and Dialytic Separation of Gases by Colloid Septa. *Transactions of the Royal Society*, 1866, p. 399.

On the Occlusion of Hydrogen Gas by Metals. *Proceedings of the Royal Society*, xvi. 422.

On the Relation of Hydrogen to Palla-

dium. *Proceedings of the Royal Society*, xvii. 212.

Additional Observations on Hydrogenium. *Proceedings of the Royal Society*, xvii. 500.

¹ The following gases were found incapable of passing through a septum of fused platinum, 1·1 mm. thick (to the extent of 0·2 cubic centimetre per hour): oxygen, nitrogen, chlorine, hydrochloric acid, vapour of water, carbonic acid, carbonic oxide, marsh-gas, olefant-gas, hydrosulphuric acid, ammonia.

gas through a metallic plate was not preceded by an actual absorption and occlusion of the gas in the mass of the metal.

APPARATUS EMPLOYED.—The mercurial trompe of Dr. Sprengel² was found to be peculiarly applicable to researches of this kind. The air in the receiver to be exhausted gained access to the Torricellian vacuum by means of a connecting-pipe, was swept on by the falling mercury, and delivered into a gas-receiver, previously filled with mercury and inverted in a mercurial trough.

When investigating the penetration of gases into a vacuous space through a metallic septum, the metal was formed into a tube closed at one end and connected by the open end with the connecting-pipe of the mercurial aspirator. Thus, in the case of the penetration of platinum by hydrogen, a tube of this metal was placed in a porcelain tube to which heat could be applied by means of a furnace. It was easy to observe that a vacuum in the platinum tube was preserved for hours, when the gas admitted to the annular space between the porcelain and platinum tubes was either atmospheric air or hydrogen, at the ordinary temperature; but when hydrogen was passed through the annular space, the platinum which was impermeable at ordinary temperatures, began to admit the gas as soon as a red-heat was attained.

After a lengthy series of experiments the following results were obtained with a tube of platinum. The tube was 0·812 metre (32 inches) in length; internal diameter, 12 millimetres; and 1·1 millimetre in thickness; the portion of the tube heated to redness was 200 millimetres in length, and had an area of 0·0076 of a square metre. The volume of hydrogen gas which penetrated in five minutes was 18·6 cubic centimetres. Hence 1 square metre of heated platinum (1·1 mm. thick) would deliver 489·4 cubic centimetres of hydrogen per minute.

A palladium tube, 1 mm. thick, when heated to redness, was penetrated by hydrogen at the great velocity of 3992·2 cubic centimetres per square metre of palladium in 1 minute. The same palladium tube was found to be permeable by hydrogen at a temperature of 240° to 260° C., at the rate of 327 cubic centimetres per square metre of palladium in 1 minute.³

In order to ascertain the amount and nature of the gas occluded, the following arrangement was adopted. The metal, in the form of a plate or wire, was introduced into a porcelain tube, glazed both inside and outside. The tube was fitted at both ends with perforated corks, cemented with fused gutta-percha, and provided with small quill tubes, the apparatus thus affording a means of heating the metal in a vacuum and also in an atmosphere of hydrogen or any gas admitted into the porcelain tube. The experimental method consists first in charging the metal under examination by heating it in an

² Researches on the Vacuum, by Hermann Sprengel, Ph.D., Journ. of the Chem. Soc. new ser. 1865, iii. 9.

³ Proceedings of the Royal Society,

xvi. 426. The stated temperatures differ slightly from those given in Graham's paper, but Roberts vouches for their accuracy.

atmosphere of gas; and, secondly, in the extraction of the gas occluded, by means of a vacuum aided by heat.

The following is a summary of the results which were obtained:—

PLATINUM.

Fused platinum occludes 0.207 of its volume of hydrogen.

Spongy platinum occludes 1.48 volume.

Wrought platinum from an old crucible 5.53 volumes. Wrought platinum in the form of tube 2.28 volumes.

OSMIUM-IRIDIUM.

The native alloy of these metals exhibits no absorbing power for hydrogen.

GOLD.

93.3 grammes of cornets (*i. e.* small flat strips of the metal rolled into a coil) from gold assays held 10.25 cubic centimetres, or 2.12 volumes of gas, 6.70 cubic centimetres of which were carbonic oxide. The amount of hydrogen occluded by gold is sensible, but does not exceed 0.48 of its volume. Probably the most interesting point connected with the occlusion of gases by gold, is presented by the fact, that the metal retains 0.2 of its volume of nitrogen.

SILVER.

The power of silver to occlude 0.7 of its volume of oxygen was conclusively established, but considering the well-known phenomenon connected with the absorption of oxygen by molten silver, it would appear desirable to extend and complete the experiments.

COPPER.

One volume of wrought copper occludes 0.306 volume of hydrogen.

IRON.

The penetration of malleable iron by hydrogen has been clearly demonstrated, and the experiments hitherto conducted have shown that pure (*i. e.* the purest commercial) iron in the form of fine wire is capable of occluding 0.46 of its volume of hydrogen.

The following most important fact was also established. Pure iron is capable of taking up at a low red-heat and of holding when cold 4.15 volumes of carbonic oxide. As Mr. Graham remarked, "The relations of the metal to carbonic oxide appear to be altogether peculiar, and they cannot fail to have a bearing upon the important process of *acieration*."

METEORIC IRON AND HYDROGEN.

It was hoped that the nature of the occluded gases would throw some light upon the origin of meteoric iron. Submitting the question

to the test of experiment, the following result was obtained:⁴—A portion of the meteorite of Lenarto, weighing 43·2 grammes, was heated in vacuo, and 16·53 cubic centimetres of gas were collected in 2 hours, 35 minutes.

This gas was found to consist of—

| | |
|----------------------|--------|
| Hydrogen | 85·68 |
| Carbonic oxide | 4·46 |
| Nitrogen..... | 9·86 |
| | <hr/> |
| | 100·00 |
| | <hr/> |

PALLADIUM.

Experiments proved that, of all metals, palladium possesses the power of occluding hydrogen in the highest degree. By slow cooling from a red-heat in an atmosphere of hydrogen, palladium foil or wire occludes no less than 900 volumes of hydrogen; and, as has already been stated, the velocity with which hydrogen passes through the walls of a tube is very considerable.

The phenomenon of the occlusion of hydrogen by palladium is also exhibited at a comparatively low temperature, the metal in the state of foil readily absorbing 600 times its volume of gas at a temperature below 100° C. Hydrogen is also largely absorbed, although less constantly, at ordinary temperatures.

The occlusion of hydrogen by palladium is most readily effected when the palladium plate constitutes the negative electrode, in acidulated water, of a Bunsen's battery of about six cells, the quantity of gas so occluded amounting to 986 volumes.

It is curious that, although the hydrogen enters the palladium, and, doubtless, pervades the mass of the metal under these circumstances, the gas does not leave the metal and escape into a vacuum at the temperature of its absorption, although it is freely evolved by the application of a gentle heat. Thus hydrogen may be present in palladium in considerable quantity without exhibiting sensible tension at low temperatures.

Hydrogen when occluded is certainly no longer a gas, and the experiments pointed to the probable existence of hydrogen in the metallic state.⁵

So large an absorption of hydrogen as 986 volumes sensibly increases the weight of the palladium. There are, however, many difficulties to be overcome before the density of the occluded hydrogen can be ascertained.

⁴ Proceedings of the Royal Society, xv. 502.

⁵ *Electrical Conductivity*.—The conducting power of several wires compared with palladium wire charged with 986 times its volume of hydrogen was found to be as follows, that of pure copper being taken as equal to 100 :—

Pure copper 100

| | |
|--------------------------|------|
| Pure palladium | 8·10 |
| Alloy of 80 % copper and | |
| 20 % nickel | 6·63 |
| Palladium + hydrogen | 5·99 |

It is evident that the conducting power of hydrogenized palladium is considerable, and tends to prove that the second constituent of the palladium wire possesses a metallic character.

One of the most remarkable facts of the entire research is the dilatation of a palladium wire when charged with gas. Thus, when a wire 609.585 millimetres long was placed as a negative electrode of a battery decomposing acidulated water, hydrogen gas was occluded. The wire was increased in length to 619.354 millimetres, which is equal to an expansion of 9.769 millimetres, and, when the hydrogen was extracted from the wire, there was found to be a *permanent shortening* from the original length of the wire amounting to 9.4 millimetres. The elongation and shortening of the wire appear to be nearly equal in amount.

After a long series of experiments the following composition was assigned to the palladium wire charged with hydrogen.⁶

| | |
|--|--------------------------|
| | In bulk. |
| Palladium | 100.000 or 90.895 |
| Hydrogenium (so called by Graham) when thus occluded) | 9.827 ,, 9.105 |
| | <hr/> 109.827 or 100.000 |

The specific gravity of the palladium was 12.3, and the weight of the wire 1.554 gramme, and its volume 0.126 cubic centimetre, the occluded hydrogen measured 120.5 cubic centimetres. The weight of the same would be 0.0108 gramme, and the volume of the hydrogenium, 0.01238 cubic centimetre (100 : 9.827 :: 0.126 : 0.01238).

The density of hydrogenium is therefore 0.872. $\frac{0.0108}{0.01238} = 0.872$.

The property of occluding hydrogen was also found to belong to palladium alloys, and indeed the expansion of the alloys by the occlusion of hydrogen is greater than in the case of pure palladium; and on expelling the hydrogen by heat, the fixed alloy returned to its original length without any further shortening of the wire, so that the embarrassing shortening of the wire disappeared. The following alloys were examined:—

| | | | |
|-----------------|--------------|-----------------|--------------|
| Palladium | 76.03 | Palladium | 75.21 |
| Platinum | 23.97 | Gold | 24.79 |
| | <hr/> 100.00 | | <hr/> 100.00 |
| Palladium | 66 | | |
| Silver | 34 | | |
| | <hr/> 100 | | |

Palladium containing 70 % of silver occluded no hydrogen whatever.

Roberts and Wright infer that the hydrogenium-palladium substance is not an alloy, because, according to their results, its specific heat is not in accordance with Kopp's law, that the specific heat of an alloy is the mean of the specific heats of its constituents.⁷

⁶ Proceedings of the Royal Society, xvii. 501.

⁷ Journ. Chem. Soc. new ser. 1873, xi. 112.

GENERAL CONSIDERATIONS ON METALLURGICAL PROCESSES.

ORES.

METALS occur in the earth either in the metallic state, or in the state of chemical combination as sulphides, oxides, and carbonates, or, more rarely, as arsenides, chlorides, sulphates, phosphates, and silicates. The term *native* is used to express their occurrence in the metallic state: thus gold and platinum occur native. Native metals are not necessarily pure: thus no instance is recorded of native gold free from silver.

The term *ore* is applied to the metalliferous matter in the state in which it is extracted from the earth by the miner.

Ores generally exist either in veins or beds. Veins have been formed by the filling up of cracks or fissures in rocks, with metalliferous, and non-metalliferous matter, i.e. matter which contains no metal, the object of extraction by the miner. Such matter is termed *vein-stuff*, *matrix*, or *gangue*. Sometimes a vein is found enlarged into cavities of considerable size filled with ore. When the vein is narrow, the rock forming its walls or cheeks must be excavated to a certain extent, and in this case the ore may, in addition to the vein-stuff proper, contain more or less of the rock which the vein traverses. Ores from beds may be mixed with the substance of the roof or floor of the mine, or, in the case of nodules arranged in beds, with the substance in which they are imbedded. It may be convenient, for the sake of brevity, to designate as *extraneous* matter, everything in the ore except the *metalliferous mineral species* which is the object of search by the miner.

This extraneous matter is separated in a greater or less degree by the mechanical processes of *dressing* practised at the mines; but in some cases it would not be expedient, even were it practicable, to effect the complete separation of this matter, which may serve an important purpose in the metallurgical treatment of the ore. Thus, in the extraction of copper from copper-pyrites, silica is essential for the removal of the iron. The extraneous matter may consist of one or more of the following substances:—Silica, in the form of quartz; various silicates, such as feldspar and mica in granite, hornblende, clay-slate, etc.; carbonate of lime, carbonate of magnesia, sulphate of baryta, fluor-spar, iron-pyrites, oxide of iron, etc.

CLASSIFICATION OF PROCESSES.

They may be divided into *dry* and *wet*, according as they are conducted without or with the agency of liquid reagents. The terms *pyro-* and *hydro-metallurgical*, have been proposed instead of dry and wet, but they possess no advantage over these short, explicit, and

generally accepted words. In some instances a metal is extracted by a combination of dry and wet processes. It is not always that a metal is required to be separated from its ore in the *metallic* state.

The various kinds of dry metallurgical processes may be classified as follows:—

I. SEPARATION OF THE METAL WITHOUT FUSION OF THE ORE.

Direct, where no reduction is required. Example: Amalgamation of auriferous quartz.

Indirect, with reduction. Example: Amalgamation of sulphuretted silver ores.

II. SEPARATION OF THE METAL WITH FUSION OF THE ORE.

Simple fusion, where no reduction is required. Example: Fusion of native gold dust or native silver.

Simple reduction, with fusion. Example: Melting native sulphide of antimony with iron.

Reduction, with volatilization of the metal. Example: Heating calcined calamine, or oxide of zinc, with carbonaceous matter.

Reduction by complex processes, with fusion. Example: Smelting sulphuretted copper-ores, or arsenical ores of nickel and cobalt.

REDUCTION.

When a metal is separated from a state of *chemical* combination, it is said to be *reduced*, and the process of separation is termed *reduction*. The agent, by which reduction is effected, is termed the *reducing agent*. Thus, when charcoal is heated with oxide of lead, carbonic acid is formed and the lead is reduced to the metallic state; or when iron is heated with sulphide of lead, sulphide of iron is formed, and the lead is also reduced to the metallic state. In these cases the carbon and iron are reducing agents. The term reduction is also used to express the *partial* separation of the electro-negative element of a metallic compound. Thus, it is usual to speak of the reduction of an oxide from a *higher* to a *lower* degree of oxidation. The metals which may be reduced from their combinations with oxygen by the action of heat alone were formerly termed *noble*, whereas the metals of which the oxides cannot be so reduced were termed *base*: thus, gold and silver are examples of noble metals, and copper and lead of base metals. When the oxides and sulphides of certain metals are heated together, complete reduction takes place, and in such cases the oxides and sulphides may equally be regarded as reducing-agents: thus when protoxide and disulphide of copper are intimately mixed together in the ratio of $2\text{CuO} + \text{Cu}_2\text{S}$ [*idem*], and then pretty strongly heated, the whole of the copper is separated in the metallic state, and the whole of the sulphur is evolved in the state of sulphurous acid. It is not correct to apply the term reduction to the mechanical separation of a metal which exists in the *metallic* state in its ore.

REDUCTION BY CARBON.—When an oxide is *easily* reducible, like oxide of lead, carbonic acid will always be formed, whatever may be the proportion of carbon. The carbon is converted directly into carbonic acid, just as when it is burned in oxygen or atmospheric air; and the temperature at which the oxide is reduced, is not sufficient to cause the reduction of the carbonic acid to carbonic oxide by the carbon present, a comparatively high temperature being required to produce that effect. When the oxide is *not easily* reducible—such as oxide of zinc—carbonic oxide will always be formed, because the temperature required for its reduction is so high, that, supposing carbonic acid in the first instance to be formed by one portion of the carbon, it would be immediately reduced to carbonic oxide by another portion of the carbon before any further reduction of the oxide could be effected. It must be borne in mind that in any merely mechanical mixtures, the oxide and carbon must exist in comparatively large particles. In these processes of reduction it is necessary to consider the effect of variation in the relative *quantities* of the agents concerned: thus, carbonic oxide reduces oxide of zinc at a high temperature, with the formation of an equivalent proportion of carbonic acid; and zinc reduces carbonic acid to carbonic oxide, with the formation of an equivalent proportion of oxide of zinc. The case is exactly analogous to the decomposition of water at a high temperature by iron, and the reduction of oxide of iron by hydrogen. Hence there should be a mixture of carbonic acid and carbonic oxide, to which zinc might be exposed at a given temperature without change; or a mixture of hydrogen and steam, to which iron might be exposed without change. Debray has investigated this subject, and obtained the following results.¹ When mixtures of hydrogen and steam are passed over heated sesquioxide of iron in the proportions of $H+HO$ [H^2+H^2O], H^2+HO [$2H^2+H^2O$], H^3+HO [$3H^2+H^2O$], black protoxide of iron is always formed, upon which the magnet has no action, which easily burns with the production of magnetic oxide, and dissolves in hydrochloric acid without the evolution of gas. In the proportion of H^4+HO [$4H^2+H^2O$], sesquioxide of iron is reduced to the metallic state. When hydrogen and steam are passed over the reduced iron in the proportions of H^3+HO [$3H^2+H^2O$], H^2+HO [$2H^2+H^2O$], $H+HO$ [H^2+H^2O], there is *perfect equilibrium*. When a mixture of carbonic acid and carbonic oxide, in the proportion of CO^2+CO [*idem*], is passed over sesquioxide of iron, the latter is reduced to the state of protoxide. This mixture is without action on metallic iron, and it reduces the oxides of nickel, cobalt, and zinc to the metallic state. H. Sainte-Claire Deville has recently shown that the action of steam upon iron, and of hydrogen upon oxide of iron, varies greatly with the temperature at which the experiments are conducted, and with the pressure or tension of the gas or vapour.²

It was maintained by Le Play³ that *solid* carbon could not directly

¹ Comptes rendus, 1857, xlv. 1018.

² Ibid. 1870, lxxi. 1105 *et seq.*

³ The following observations are ab-

stracted from the excellent paper of Gay-Lussac, entitled "Remarques sur la Théorie de M. Le Play, Ingénieur des

effect the reduction of metallic oxides. His conclusion was founded on the following considerations:—1. He remarked with astonishment that in zinc-works it was regarded as a matter of indifference whether the ore and carbonaceous reducing-agent were intimately mixed or not. The ore consists essentially of oxide of zinc, from which the metal is always reduced by carbonaceous matter. Le Play then inferred that *carbonic oxide alone* was the reducing-agent. 2. He ascertained, during numerous metallurgical travels, that in all blast-furnaces in which the oxides of iron, lead, copper, and tin are reduced, there is no appreciable contact between the ores and the charcoal; that the operation does not even succeed when the mixture is as complete as possible; and that on the contrary, the more insignificant the contact the better will be the working of the furnace. 3. Le Play and Laurent reduced various oxides and salts by heating them in a porcelain tube through which passed a current of carbonic oxide. Thus hæmatite and a crystal of specular iron-ore were perfectly reduced by this means; so also were the oxides of cobalt, nickel, and tin. Tungstic acid was likewise reduced to the metallic state, but the oxides of cerium, chromium, and titanium suffered no change. Crystals of sulphate of baryta and sulphate of lime were converted into sulphides. 4. They heated in a porcelain tube a crystal of sesquioxide of iron and a piece of charcoal, each being contained in a separate platinum trough in order to prevent contact, and the oxide was perfectly reduced to the metallic state.

In all these cases it is very easy to conceive, as Gay-Lussac remarks, that reduction may be effected by carbonic oxide when it is capable of reducing the oxide of the metal. This gas, forming an atmosphere around the pieces of ore and penetrating into the smallest interstices, ought to effect a more rapid reduction than charcoal, with which the contact must be less intimate. Let a piece of charcoal and a mass of metallic oxide be kept separate and heated in a confined space from which gas may escape; they will react upon each other, provided the space were originally filled with carbonic oxide, carbonic acid, or even atmospheric air, and provided also the temperature be sufficient to convert carbonic acid into carbonic oxide by contact with charcoal. Carbonic oxide reduces the metallic oxide with the formation of carbonic acid; this carbonic acid is converted back into carbonic oxide by contact with charcoal at a high temperature, and so the action is propagated continuously, carbonic oxide being the vehicle by which the oxygen of the oxide and the solid carbon are combined.

Now, because reduction may be effected under the conditions stated by the agency of carbonic oxide, it by no means follows that solid carbon is incapable of reducing oxides by direct contact. On the contrary, Gay-Lussac states that, when strongly calcined lamp-black is heated with easily reducible oxides—such as oxides of silver, mercury, copper, lead, bismuth, etc.—reduction takes place below a

Mines, touchant la réduction des oxydes métalliques par le charbon." Ann. de Chim. et de Phys. s. 3, 1846, xvii. 221.

I have adhered, as far as practicable, to the language of Gay-Lussac.

red-heat, and much below the temperature at which carbon can convert carbonic acid into carbonic oxide, only absolutely pure carbonic acid being evolved. With all these oxides reduction is directly effected by carbon, and cannot be attributed to carbonic oxide, which is not present. No doubt, he continues, carbonic oxide would perfectly well reduce these oxides at a suitable temperature, and, assuredly, more rapidly than carbon; but that is not the question. It is sufficient to demonstrate that carbon alone, at a very moderate degree of heat, reduces metallic oxides without the intervention of carbonic oxide or any other elastic fluid.

The temperature at which oxide of silver may be reduced by solid carbonaceous matter has been investigated in my laboratory by A. Dick. Oxide of silver was prepared by precipitation with potash from nitrate of silver. Intimate mixtures were made of 116 grains of the oxide with 6 of wood-charcoal, of 116 of oxide and 6 of carbon obtained from the imperfect combustion of coal-gas, and of 116 of oxide with 3 of the same carbon. These mixtures were heated in a hot-air bath. The first exploded quietly at 262° C., and another similar mixture at 270° C.; the second exploded rather violently at 178° C.; the third exploded at 185° C.; and in two repetitions of the experiment with the last mixture the explosion occurred at 172° C. and 178° C. respectively. In all the experiments the metal remained in the state of fused globules. No oxygen was evolved from the oxide heated *per se* at these temperatures. Perhaps an objection might be raised against the conclusiveness of these experiments on the ground that the carbon employed was not free from hydrogen.

"But, independently of oxides," continues Gay-Lussac, "which carbon directly reduces at a temperature below that at which it decomposes carbonic acid, there are many others which resist carbonic oxide, even at a very high temperature, and are yet reducible by carbon. Such are the oxides of manganese, chromium, cerium, titanium, potassium, etc.

"Since, then, carbon directly reduces oxides which require only a moderate heat, and those which require a very high temperature—conditions in which carbonic oxide produces no effect—is it not evident that it must reduce oxides at an intermediate degree of heat when carbonic oxide is able to effect reduction at that temperature? But in stating that carbon would then act concurrently with carbonic oxide in the reduction of oxides, we only wish to establish the fact, as we are convinced that in consequence of the contact of that gas with the ore being much more intimate than can possibly be the case with carbon, it ought to effect reduction with much greater rapidity."

"Le Play was misled by seeing the reduction of oxides apparently effected on a very large scale in metallurgical works by the sole agency of carbonic oxide, and he erroneously inferred that the action of carbon was nothing because it seemed to him insignificant. The difference in the action of these two bodies, whenever they are in the presence of an oxide, which each has the power of reducing, is, without

doubt, very great, but it is not the less due to purely mechanical causes, and the action of the one body ought not to be ignored, because, in particular cases, it may be much inferior to that of the other."

When a piece of hæmatite, even of large size, is kept exposed to the action of carbonic oxide at a high temperature during a sufficient time, it may be completely reduced to the metallic state even to the very centre, and yet metallic iron at the same temperature will reduce carbonic acid. Supposing the reducing action of carbonic oxide to be equal in power to the oxidizing action of carbonic acid, then no action should take place when a molecule of oxide of iron, or one of metallic iron, is heated in the presence of a mixture of one molecule of carbonic oxide with one of carbonic acid. "If we now conceive," says Gay-Lussac, "a molecular pore to have become free by the abstraction of a molecule of oxygen which filled it, and a molecule of carbonic oxide to have been introduced instead, there will be no reason why it should act on a neighbouring molecule of oxide; for, if the reduction were possible, a molecule of iron and a molecule of carbonic acid would be in the presence of each other, and should just as well, by their reciprocal action, reproduce oxide of iron and carbonic oxide. In order that, according to the present supposition, reduction might occur, several molecules of carbonic oxide should find their way into the molecular pore, which may well be conceived to be impossible. Hence, in the present example, and many others of a similar kind, carbonic oxide cannot penetrate into the interior of masses and effect reduction. And yet there is no doubt that it is the chief agent in the reduction of iron ores, because it finds, not molecular pores, but innumerable fissures in the ore, which facilitate its access in mass to each molecule. This example manifests the inefficacy of carbonic oxide, even in circumstances in which its power suffices for reduction, and that its action is not so simple, so heroic, or so general as MM. Le Play and Laurent have thought."

SMELTING.

The term is derived from the German verb *schmelzen*, to melt. It is applied to a process, or series of processes, by which a metal or metallic compound is separated by fusion from its ore on the large scale.

FLUX AND SLAG.—The following illustration will serve to explain the meaning of these terms, which are in constant use. In auriferous quartz the gold exists in the metallic state, and is diffused through the mass in particles. When such quartz, either in lumps or in the state of the finest powder, is heated to a degree far above the melting-point of gold, perfect separation of the metal cannot occur, because the melted particles are surrounded by solid quartz, and cannot therefore subside and unite. If the gold were present in large quantity, it is true that, by stirring, it might be imperfectly collected together; but by the addition of carbonate of soda a fusible silicate of soda would be formed, and the melted gold, having a much higher specific gravity than silicate of soda, would immediately sink and unite

into one mass at the bottom. The carbonate of soda in this case would be designated a *flux*, and the resulting silicate of soda a *slag*. Other matters, such as oxide of iron, lime, clay, etc., would act in a similar manner to carbonate of soda, that is, they would form fusible compounds or slags with the quartz and so allow the gold to settle down.

The nature of the flux must obviously vary with the nature of the extraneous matter in the ore. In the case of auriferous quartz it is essential that the quartz should be wholly and completely fused, otherwise a sensible amount of gold might remain imprisoned in any unfused pieces. However, it is not necessary that in every smelting operation the fusion of extraneous matter should be so completely effected. In one process in particular we shall find that pieces of quartz as large as nuts remain diffused through a slag, producing a pseudo-porphyrific appearance. The slag in which they are imbedded having itself been well melted, the metallic matter, in consequence of its exceeding in specific gravity both the slag and the quartz, has, with the exception of what may be present *within* the latter, been enabled to subside.

REGULUS.—In the smelting of certain sulphuretted ores the product obtained in the first instance is a *sulphide* of the metal; and this product has received different names in different metallurgical works. In English copper-works the word *metal* is commonly used to denote compounds of this kind, that of *regulus* being applied in a specific sense to certain kinds of *metal*. I shall, however, adopt the word *regulus* in the present work as a generic appellation for such products. The Germans designate regulus by the synonymous terms *Stein* and *Lech*, and the French by the term *matte*. It is frequently the case that in one smelting operation *slag*, *regulus*, and reduced metal are obtained, which are superposed in the order mentioned, which is that of their respective specific gravities.

SPEISE.—In the smelting of arsenical ores the product obtained in the first instance is an *arsenide* of the metal, which the Germans call *Speise*, a convenient word now in general use. Products occur in certain metallurgical operations, in which compounds of antimony and molybdenum analogous to those of arsenic are produced; and such compounds will be included in the general term *speise*. In one smelting operation may be obtained *slag*, *regulus*, *speise*, and reduced metal.

ROASTING.

This term, with which *calcination* is occasionally used as synonymous, is applied to processes which in nature and object may differ much from each other.

The objects of roasting may be generally stated as follows:—

- I. The simple expulsion of matter, capable of being separated by heat alone. Example: Heating calamine, which is carbonate of zinc, in order to expel carbonic acid.
- II. The expulsion of matter, capable of being separated by the

conjoint action of heat and atmospheric air, and the substitution of oxygen for the matter so expelled. Example: Heating galena, which is sulphide of lead, in contact with atmospheric air, in order to expel sulphur, and to form oxide of lead.

- III. The simple addition of oxygen, without the separation of any constituent of the substance operated upon. Example: Heating "tap-cinder," which is silicate of protoxide of iron, in contact with atmospheric air, in order to convert the protoxide into sesquioxide.

Roasting may be conducted in the open air by piling the ore mixed with fuel in large heaps, or in flat-bedded reverberatory furnaces. A reverberatory furnace consists essentially of three parts—a fireplace at one end, a stack or chimney at the other, and a bed between the two, on which the matter is heated. The fireplace is separated from the bed by a low partition-wall, called the fire-bridge, and both are covered by an arched roof, which rises from the end wall of the fireplace and gradually dips towards the further end of the bed connected with the stack. On one or both sides of the bed, or at the end near the stack, are openings through which the ore, spread over the surface of the bed, may be stirred about and exposed to the action of the air. The matter is heated in such a furnace by flame, and is kept from contact with the solid fuel. The flame in its course from the fireplace to the stack is reflected downwards or *reverberated* on the ore spread over the bed, whence the name *reverberatory* furnace.

In roasting in reverberatory furnaces, the object is generally the expulsion of certain volatile matters, and the oxidation, in greater or less degree, of the residue. The ore should be spread uniformly over the bed, and stirred or raked about from time to time, in order freely to expose every part in succession to the action of the air. The heat should be gradually raised; and in the case of ores which melt or soften when heated, care must be taken to prevent *clotting*, by suitably regulating the temperature and stirring frequently. When sulphuretted or arsenical ores are roasted until no further evolution of sulphurous acid or arsenious acid takes place, the roasting is termed *sweet* or *dead*. In some cases *sweet* roasting is necessary, in others not; but when necessary, the ore should be reduced to fine powder. The rapidity of roasting will depend upon the state of division of the ore, upon the temperature, and upon the frequency with which the action of the air is promoted by stirring. When an ore is allowed to *clot* during roasting, the process of oxidation will obviously be much retarded.

DISTILLATION AND SUBLIMATION.

In the metallurgical treatment of the ores of certain volatile metals, the metal is volatilized and its vapour condensed. When the vapour passes down through the bottom of the vessel containing the ore, the process is called distillation *per descensum*; but when the vapour passes out at or near the top, the process is called distillation

per ascensum. The term sublimation is usually applied to the volatilization of a solid substance by heat, and its condensation in a solid state in the upper part of the apparatus employed.

LIQUATION.

When an ore or mixture of metals, containing ingredients differing sensibly in fusibility, is exposed to a degree of heat sufficient only to melt the most fusible, which flows away from the unmelted mass, the process is termed liquation.

SLAGS.

UNDER this head will be presented only general considerations concerning slags, and an account of particular slags will be given in the descriptions of the various metallurgical processes in which they are produced.

Silica plays a very important part in numerous metallurgical operations in the formation of slags, which indeed, excepting those produced in processes of assaying, and, in a few instances, on the large scale, are always silicates.

MODES OF FORMATION OF SILICATES.

Silicates may be formed either in the *dry* or in the *wet* way; but in metallurgical operations they are always formed in the *dry* way. Silica readily combines with a metallic oxide, when an intimate mixture of the two is heated to the right degree, provided the oxide is not reducible *per se* at or below the temperature required for combination. Fusion is not necessarily required to produce combination. Thus, when certain mixtures of silica and lime are strongly heated, there is not the slightest indication of fusion, yet it is certain that the silica has entered into combination; for, when the product is acted upon by hydrochloric acid, silica is separated in a *gelatinous* state, which is sure evidence of its having been in a state of chemical combination. Again, silicate of protoxide of cobalt, of a fine purplish-red colour, is produced by heating a mixture of fine siliceous sand and that oxide, for a long time, to a temperature below the melting-point of the silicate. When a silicate is formed by heating its constituents together, so as to cause combination, either without fusion or with only incipient fusion, the process is termed *fritting*. In the case of an easily fusible oxide, that is, one which melts at a comparatively low temperature, like protoxide of lead, for example, fritting is advantageous; because the silica and the oxide in the mixture, which is assumed to be intimate, are thereby kept well in contact with each other, which would not be possible if the temperature were raised to a degree sufficient thoroughly to melt the oxide, so as to allow it by

virtue of its high specific gravity, as compared with that of silica, to separate and collect towards the bottom of the vessel employed in the operation.

Silicates in the *wet* way are formed by double decomposition, as, for example, by adding an aqueous solution of silicate of soda (soluble glass) to an aqueous solution of a metallic salt. Thus, a beautiful greenish-blue silicate of protoxide of copper may be so formed, which, after having been washed and left to dry slowly, resembles the natural mineral, termed chrysocolla.

COMPOSITION OF SILICATES.

Silicates may be divided into anhydrous and hydrous silicates: thus, augite and feldspar are examples of the former, electric calamine (smithsonite) and porcelain clay are examples of the latter. All silicates produced in metallurgical processes by the action of heat are anhydrous, though not necessarily so, as Bunsen has shown that a hydrous silicate of lime may be prepared at a red-heat. When a finely pounded mixture, consisting of 2 parts of lime and 10 of silica by weight, is introduced into 90 parts of caustic potash melted in a silver capsule, and the whole is allowed to cool slowly, after having been kept for some time at a strong (?) red-heat in a muffle, a mass is obtained, which, when treated with water, leaves a network of prismatic crystals, frequently 4 or 5 lines in length, partly attached to the sides of the capsule. These crystals are hydrous silicate of lime, mixed with some carbonate of lime, and their composition is expressed by the formula—



They were found on analysis to consist of—

| | |
|-----------------------------------|--------|
| Silica | 27.215 |
| Lime | 22.241 |
| Potash | 0.733 |
| Water separated at 109° C..... | 36.915 |
| Water separated by ignition | 9.508 |
| Carbonate of lime..... | 2.603 |
| | <hr/> |
| | 99.215 |

This hydrous silicate of lime loses the whole of its water below a red-heat after the potash, in which it was formed, has been dissolved out.⁴ It is scarcely necessary to call attention to the fact that water cannot be separated by heat from hydrated oxide of potassium or potash.

Silicates are either crystallized or amorphous; feldspar (silicate of alumina and potash) is an example of the former, and window-glass (silicate of lime and soda) an example of the latter.

The bases which most frequently occur in slags are lime, magnesia, protoxide of manganese, protoxide of iron, potash in small quantity,

⁴ Scientific Memoirs, 1853, p. 67.

and alumina. Both the silica and the bases are derived from the extraneous matter in the ore, the ashes of the fuel, the flux added, and, in a certain degree, from the materials of which furnaces are constructed. Silicates, of which the constituents are derived from these sources, may be produced in smelting the ores of any *fixed* metal; and such silicates only will be considered in this place: silicates which are formed in special metallurgical processes will be described in due course. The extraneous matter of an ore may be fusible *per se*, in which case no flux would be necessary. It is only in blast-furnaces that the ashes of the fuel enter into the composition of the resulting slag.

ATOMIC CONSTITUTION OF SILICATES.

The old formula of silica, SiO^2 , will be adopted in this work concurrently with the new formula, SiO^2 . Our knowledge of the *rational* constitution of silicates, which contain bases both of the RO and $\text{R}'\text{O}^2$ types, is far from satisfactory. Thus alumina, which belongs to the latter type, certainly in many cases acts the part of the electro-negative constituent, or acid, as in the spinels, for example. It has, however, been the custom to regard alumina as an electro-positive constituent in silicates in which bases of both types are present: but whether this view is in all cases correct seems doubtful. However, there can be no doubt that alumina does act the part of base in compounds from which the RO type is absent, as in porcelain-clay, for example.

The nomenclature used by different writers in respect to silicates is not uniform. Thus, a silicate in which the oxygen of the base is to that of the acid as 1 : 3 is termed a *neutral silicate* by some and a *tri-silicate* by others.¹ Various relations may occur in silicates between the base and the acid, as, for example, the following:—

SILICATES CONTAINING A BASE OF THE RO TYPE.

| Silica = SiO^2 . | | Silica = SiO^2 . |
|--|--|-------------------------------|
| 1. $3\text{RO}, \text{SiO}^2$ (tribasic, or mono-, silicate) | | $2\text{RO}, \text{SiO}^2$. |
| 2. $2\text{RO}, \text{SiO}^2$ (bibasic, or sesqui-, silicate) | | $4\text{RO}, 3\text{SiO}^2$. |
| 3. $3\text{RO}, 2\text{SiO}^2$ (sesquibasic, or bi-, silicate) | | RO, SiO^2 . |
| 4. RO, SiO^2 (neutral, or tri-, silicate) | | $2\text{RO}, 3\text{SiO}^2$. |

Some metallurgical writers have used a particular method of notation to express the composition of the silicates of common occurrence. Single letters are employed as symbols both of bases and silica. Thus, C, M, A, S, denote lime, magnesia, alumina, and silica, respectively. The relation between the oxygen of the base and that of the acid is indicated by small index letters placed on the right near the top of each symbol, except in the case of unity, and then the index is omitted. By this method the formula $3\text{CaO}, 2\text{SiO}^2$

¹ Scheerer, *Lehrbuch der Metallurgie*, i. 32; Rammelsberg, *Lehrbuch der chemischen Metallurgie*, p. 30.

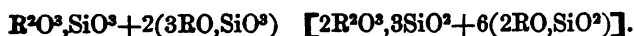
would be expressed by CS^2 ; that of $3MgO, SiO^2$ by MS ; and that of $Al^2O^3, 2SiO^2$ by AS^2 . The following are illustrations of this method of notation :—

1. RS Mono- or singulo-, silicate.
2. R^2S^2 Sesqui-silicate.
3. RS^2 Bi-silicate.
4. RS^3 Tri-silicate.

Slags may consist of a single silicate, of a combination of silicates, or of a mixture of silicates; of a single silicate, or mixture of silicates, and what is commonly understood by the term foreign matter; and perhaps of a solution of one silicate in another. Slags may occur distinctly crystallized, and yet not have a perfectly definite constitution, owing to the presence of enclosed foreign matter, which can in no way enter into their formulæ. The same fact is exemplified in many well-crystallized natural minerals. A slag which occurs crystallized in perfectly-defined and translucent square prisms, and which is produced in the blast-furnaces of South Staffordshire, may serve as an illustration. The following is one of several analyses of this kind of slag made by myself many years ago :—²

| | | Oxygen. |
|---------------------------|-------------------|---------|
| Silica | 38·05 | 19·76 |
| Alumina | 14·11 | 6·59 |
| Lime..... | 35·70 | 10·03 |
| Magnesia..... | 7·61 | 2·94 |
| Protoxide of manganese... | 0·40 | 0·09 |
| Protoxide of iron | 1·27 | 0·29 |
| Potash | 1·85 | 0·31 |
| Sulphide of calcium | 0·82 | |
| | <hr/> 99·81 <hr/> | |

The oxygen of the silica is very nearly equal to that of the bases, but the oxygen of the RO , or lime type of, bases is rather more than double that of the R^2O^2 , or alumina type of, bases. The constitution of this slag may be expressed by the formula—



It is the formula assigned by Damour to the natural mineral humboldtilite. The sulphide of calcium—it is inferred, but not proved, that the sulphur exists wholly in this state of combination—cannot be regarded as in any way connected with the formula. What the state of combination of the potash may be is not certain.

The following composition of another slag affords a more striking illustration of the point under consideration. It was produced in the process of *puddling* in an iron forge.

² Report on Crystalline Slags, by the Author and W. H. Miller, M.A., F.R.S., &c., of Cambridge. Brit. Assoc. Rep. 1846.

COMPOSITION OF SLAG PRODUCED IN PUDDLING.

| | | Oxygen. |
|------------------------------|--------------------|---------|
| Silica | 23.86 | 12.41 |
| Protoxide of iron | 39.83 | 9.07 |
| Sesquioxide of iron | 23.75 | 7.28 |
| Protoxide of manganese | 6.17 | 1.38 |
| Alumina..... | 0.91 | 0.42 |
| Lime | 0.28 | 0.08 |
| Magnesia | 0.24 | 0.09 |
| Phosphoric acid..... | 6.42 | 3.60 |
| Sulphide of iron | 0.62 | |
| | <hr/> 102.08 <hr/> | |

Now this slag was well crystallized, and the crystals were found by Professor Miller, of Cambridge, closely to resemble olivine in their form; and, from the analysis of the crystals of another similar slag, which were measured, and which contained only 1.34 per cent. of phosphoric acid, there is no doubt that it *originally* consisted essentially of tribasic silicate of protoxide of iron. The phosphorus existed chiefly as phosphoric acid in combination with one or both oxides of iron, and in part probably in the state of phosphide of iron; but in whatever state it was present, it must be regarded as *foreign* matter. If any phosphide of iron were present, the excess obtained in the analysis would be due in a certain degree to the oxidation of that phosphide during the process of analysis. The existence of the sesquioxide of iron admits of easy explanation. When silicate of protoxide of iron is heated to redness, with access of air, it increases in weight, owing to the absorption of oxygen; and the slag in question had, subsequently to its formation in the puddling-furnace, been long exposed to this condition of oxidation, during which it must have absorbed oxygen with the partial conversion of the protoxide into sesquioxide of iron. The crystals should, therefore, be considered as pseudo-morphous. It will be shown in another part of this work, that protoxide of iron in combination with silica in a slag of this kind may, by sufficiently long calcination, with access of air, be wholly converted into sesquioxide; but at the same time the silica is set free, that is, it no longer exists in a state of chemical combination.

DISPLACEMENT OF BASES IN SILICATES.

The base of a silicate may be displaced by another base having a greater affinity for silica, just as one base may be displaced by another in solutions of salts. Thus, Ebelmen found that protoxide of iron might be completely separated from *refinery*-slag, of the formula $3\text{FeO}, \text{SiO}^2$ [$2\text{FeO}, \text{SiO}^2$], by lime. This slag was strongly heated with a piece of marble of its own weight in a platinum capsule during three days continuously. On removing the capsule from the furnace, it was found that the marble had entirely disappeared. The product, which was black, was treated first with cold dilute hydrochloric acid, and then with an alkaline solution to dissolve the gelatinous silica which had separated. The insoluble residue was a magnetic crystalline powder, which, under the microscope, was seen to consist of

octahedral crystals of magnetic oxide of iron mixed with amorphous sesquioxide of iron: by digestion with strong hydrochloric acid it wholly dissolved, and the solution contained proto- and sesqui-chloride of iron. The result was confirmed by a second experiment. Ebelmen made experiments of a similar kind upon various borates, of which the results possess a high degree of interest. Thus, he obtained crystals of magnesia, of oxide of nickel, cobalt, and manganese, and of perowskite (titanate of lime), of which, on a visit to him at the Sèvres Porcelain Works in 1851, he showed me beautiful crystals in the platinum capsule just as it had left the furnace.³

When metallic iron is immersed in a molten slag consisting of silica in combination with protoxide of iron and dioxide (*i.e.* red oxide) of copper, copper is precipitated in the metallic state, just as it would be from an aqueous solution of its sulphate or chloride by the same metal; and, as will hereafter be seen, it has been proposed to apply this reaction to the extraction of copper on the large scale from certain of its ores.

CHARACTERS OF SLAGS.

Slags occur either more or less distinctly crystallized, in the state of glass, or non-crystalline and stone-like. A single piece of slag may present all these characters. Rapid cooling tends to produce the glassy state, and slow cooling the crystalline state. Hence, if a piece of slag is crystalline in one part and glassy in another, the outer part, which has been exposed to the air, or come in contact with the ground or other cooling surface, will always be the glassy one. In some slags isolated crystals are scattered through a glassy matrix—an appearance which may frequently be observed in slags from the blast-furnaces of South Staffordshire; in others, spheroidal masses, consisting of radiating fibrous crystals, and varying in diameter from that of a pea to an inch and upwards, are imbedded in a similar matrix; and in others again the whole mass is confusedly crystalline.⁴

CRYSTALLIZATION OR DEVITRIFICATION OF CERTAIN SILICATES.

If glass, especially crown- or bottle-glass, which is composed of silica, soda, and lime, is subjected to slow cooling during solidification after fusion, or, after it has become cold and solid, is re-heated and kept for a long time at a high temperature, but below its fusing-point, it passes from the vitreous to the crystalline state, when it is said to be *devitrified*. The so-called porcelain of Réaumur is only devitrified glass. Common barley-sugar, which is sugar in a glassy state, the result of rapid cooling after melting, always becomes devitrified or crystalline on keeping, even at the ordinary temperature. Very beautiful and instructive illustrations of the crystallization of

³ Recueil des Trav. scient. 1855, i. 210. | la Couleur bleue des Laitiers," by M. J.
⁴ See an interesting paper, "Sur la | Fournet, Ann. de Chim. et de Phys. s. 3,
 Cristallisation des Silicates vitreux et sur | 1842, iv. 370.

glass may be frequently obtained in glass-houses where either crown- or bottle-glass is made; flint-glass, which is composed of silica, potash, and protoxide of lead, rarely occurs crystallized. In pieces of crown-glass the formation of crystals may be traced; little groups of delicate radiating prisms at first appear, which gradually increase in number and size until they finally coalesce into a white opaque mass. In bottle-glass the spheroidal masses are sometimes formed in parallel layers, producing a structure like that of Lipari obsidian. Sections of devitrified glass are beautiful objects under the microscope when seen by polarized light.

If a slag has a definite chemical constitution, it may, under favourable conditions of cooling, be converted into one mass of similar crystals; but if it has not such a definite chemical constitution, crystals may be separated from the mass differing sensibly in composition from the original slag. The following analytical results relating to this interesting subject deserve attention. A pot of glass consisting chiefly of silica and lime having been accidentally subjected to slow cooling, there was found at the bottom of it greenish transparent glass, enclosing opaque, white, perfectly crystalline, globular nodules, some isolated and others coalescing, the surface of which, when seen under a lens, appeared drusy. The nodules on fracture presented a radiated structure and a fatty lustre; they were harder and less fusible than the surrounding glass; and their specific gravity was 2·77. Analyses both of the nodular or devitrified and the transparent glass were made by Kersten, whose results are as follow:—⁶

| | I. Crystallized glass. | II. Transparent glass. |
|------------------------------|---------------------------|---------------------------|
| Silica | 58·80 | 60·39 |
| Alumina..... | 3·30 | 6·10 |
| Lime | 20·20 | 13·40 |
| Protoxide of iron | 3·51 | 3·10 |
| Protoxide of manganese | 4·20 | 2·20 |
| Magnesia | 0·50 | 0·40 |
| Potash | 2·70 | } 14·41 |
| Soda | 5·50 and loss | |
| | <hr/> 98·71 | <hr/> 100·00 |
| Specific gravity | 2·77 | 2·63 |

In each of these analyses the ratio between the oxygen of the silica and that of the bases is 3 : 1; and the formula which Kersten deduced for the crystallized glass is $\text{Al}^2\text{O}^3, 3\text{SiO}^2 + 18(\text{RO}, \text{SiO}^2)$ [$2\text{Al}^2\text{O}^3, 9\text{SiO}^2 + 18(2\text{RO}, 3\text{SiO}^2)$], in which R = Ca, Fe, Mn, Mg, K, Na.

Terreil examined bottle-glass which had been left to cool in the pots in consequence of repairs being required in the furnace. He analysed a specimen of crystallized or devitrified glass, and a specimen of transparent glass made from the same materials and in the same proportions. The results are as follow:—

⁶ Erdmann's Journal, 1843, xxix. 145.

| | I. Crystallized glass. | II. Transparent glass. |
|---------------------|---------------------------|---------------------------|
| Silica | 55·85 | 56·84 |
| Lime..... | 24·14 | 21·15 |
| Magnesia..... | 7·63 | 6·37 |
| Alumina | 2·22 | 3·64 |
| Oxide of iron..... | 1·06 | 2·59 |
| Soda..... | 8·47 | 8·69 |
| Potash..... | 0·63 | 0·40 |
| Manganese..... | traces | traces |
| | <hr/> 100·00 | <hr/> 99·68 |
| Specific gravity... | 2·824 | 2·724 |

He analysed all the materials from which the glass was made, calculated the composition from the proportions in which they were mixed, and found it to agree with that obtained by analysis; and ascertained that there was no loss by volatilization during the process of devitrification. The oxygen of the silica is to that of the bases nearly as 9 : 4; whence he deduced the formula—



RO = CaO, MgO, NaO. Calculating from this formula, and neglecting the alumina and oxide of iron, the composition would be—

| | |
|----------------|--------------|
| Silica | 55·97 |
| Lime | 23·04 |
| Magnesia | 8·23 |
| Soda | 12·76 |
| | <hr/> 100·00 |

The crystallized glass may be regarded as augite, in which a portion of the magnesia is replaced by soda.

Terreil also analysed the crystallized and transparent portions in a single lump of a piece of glass. The results are as follow :—

| | I. Crystallized glass. | II. Transparent glass. |
|---------------------|---------------------------|---------------------------|
| Silica..... | 63·67 | 62·40 |
| Lime..... | 18·65 | 18·14 |
| Magnesia | 6·12 | 4·47 |
| Alumina | 4·98 | 7·21 |
| Oxide of iron..... | 0·71 | 2·66 |
| Alkalies..... | 5·87 | 5·12 |
| Manganese | traces | traces |
| | <hr/> 100·00 | <hr/> 100·00 |
| Specific gravity... | 2·610 | 2·857 |

In these analyses the ratio between the oxygen of the silica and that of the bases rather exceeds 9 : 4.⁶ The mixture used in the making of this glass differed from that used for the first.

⁶ Note sur un verre à bouteille cristallisé. Par M. A. Terreil. Comptes rendus 1857, xlv. 693. Kopp und Will's Jahresbericht, 1857, p. 165.

A fact first observed by Le Blanc is confirmed by these analyses, namely, the alumina and oxide of iron appear to become concentrated in the transparent glass—or, as it might be termed, *mother-liquor*.

According to Fournet, the same silicates are more fusible in the *vitreous* than in the *crystallized* state. By devitrification glasses become harder, specifically heavier, better conductors of heat and electricity, and much less fusible; and, moreover, when devitrified glass is heated, it does not soften before it melts, but passes suddenly into the liquid state.

The statement that devitrified glass decreases in specific gravity when it becomes vitreous, agrees generally with the observations of Delesse on obsidians or volcanic glasses, for he only met with a few exceptions to the rule amongst these substances.⁷ But it is opposed to the results recently obtained by Mr. W. D. Herman, who has at my request investigated the question at large glassworks, to which he is attached in the capacity of chemist. He informs me (October 10, 1872) that he has repeatedly ascertained the specific gravity of crystallized and vitreous portions of glass from the same mass and in different specimens. He found, that taking the mean of many results, none of which differed from each other more than in the third decimal, the specific gravity of the vitreous glass was 2.5398, and that of the crystallized glass was 2.5196. The glass upon which he operated was composed of silica, soda, and lime in certain fixed proportions.

Glass, which after solidification has been allowed to cool quickly, as, for example, by free exposure to the air—that is, unannealed—has a slightly lower specific gravity than when it has been very gradually cooled, so as to become annealed, but the cooling has not been so slow as to induce crystallization.⁸

As to difference between the melting-points of crystallized and vitreous glass, it will probably be found that glass is far from peculiar in that respect. I remember well being much struck with observing that crystals of acetic acid were permanent at temperatures at which the same acid when liquefied would not again crystallize.

The condition, which seems to be essential for the devitrification of glass, is long continued exposure to a temperature sensibly below its melting-point, yet high enough to communicate to its particles sufficient freedom of movement to enable them to obey the law of crystallogenic segregation, just as in the analogous case of a metallic mass subjected to similar conditions of temperature. But as some glasses may consist of the intermixture of two or more silicates of different fusibility, or, it may be, of the solution of one silicate in another, devitrification may possibly in such cases be analogous to the crystallization of bodies from ordinary solutions.

⁷ Fournet, Journ. des Mines, 1811, xxx. 161–254. Comptes rendus, 1861, liii. 179. Experiments on Whinstone and Lava. By Sir James Hall, Bart. Trans. Roy. Soc. of Edinburgh, 1798.
⁸ Chevandier and Wertheim, Ann. de Chim. et de Phys. s. 3, 1847, xix. 137. Riche, *ibid.* s. 4, 1873, xxx. 415.

POROSITY OR VESICULARITY OF SLAGS.

Slags may be more or less *porous* or *vesicular*. I have found pieces of blast-furnace slag in South Staffordshire presenting a *cellular* structure, which in regularity might almost be compared to honey-comb. H. Sainte-Claire Deville has arrived at the conclusion, from experimental evidence, that all glasses in a molten state can absorb gases, which on cooling are either evolved, or, as in the case of obsidian, may be retained and subsequently disengaged at a gentle heat, thereby imparting a pumice-like structure.⁹ On this principle the remarkable cellular structure of the slag above mentioned might be explained. When some kinds of blast-furnace slag are allowed to flow from the furnace into water, they swell up immensely, forming a white, very light, pumice-like mass.

HAIR-LIKE FORM OF SLAGS.

Occasionally specimens of slag may be obtained from blast-furnaces in the form of spun-glass. Owing to some accidental condition, the melted slag has actually been spun, as it were, by the blast, just as glass is spun by a wheel. I have received beautiful specimens of this kind from my deceased friend, Mr. Levick, of the Blaina and Cwm Celyn Ironworks, and also from Prussia.

While on a visit to the Dowlais Ironworks in 1870, I had the opportunity of seeing how this hair-like slag was formed. A little slag leaked out through the clay-stopping round one of the twyers at the back of a hot-blast furnace, and in the act of escaping was caught by the regurgitating blast and blown out into fine threads, intermingled with minute adherent globules of glassy slag. I collected a considerable quantity of it, and I may mention that it should be handled with caution, as the fine short threads easily penetrate the skin and cause not a little irritation for the time. This slag so exactly resembles in appearance the capillary volcanic glass, known as Pelé's hair, from the volcano of Kilauea in the Island of Hawaii, in the Pacific Ocean, that seen side by side they cannot be distinguished from each other. The actual formation of this mineral has been accurately observed on the spot, and well described by Dana. "At one of the pools," he says, "the formation of Pelé's hair (Pelé being the local name of a goddess), or capillary volcanic glass, was in progress. It covered thickly the surface to leeward, and lay like mown grass, its threads being parallel, and pointing away from the pool. On watching the operation a moment, it was apparent that it proceeded from the jets of liquid lava thrown up by the process of boiling. The currents of air blowing across these jets bore off small points, and drew out a glassy fibre, such as is produced in the common mode of working glass. The delicate fibre floated on till the heavier end brought it down, and then the wind carried over the lighter capillary extremity. Each fibre was usually ballasted

⁹ Kopp und Will's Jahresbericht, 1863, p. 91.

with the small knob which was borne off from the lava-jet by the winds."¹

BRITTLENESS AND TOUGHNESS OF SLAGS.

In respect to *brittleness* and *toughness* there is great variation in slags. A slag will generally be tough in proportion to its slowness of cooling, just as devitrified glass, which is the result of slow cooling, is extremely tough as compared with the original glass. The slag which has been previously mentioned (p. 49), and of which the formula is



is very brittle both in the crystallized and glassy state; whereas another crystallized slag from the same furnaces, of much less frequent occurrence, is extremely tough: its formula is



In both formulæ $R^2O^3 = Al^2O^3$ and $RO = CaO, MgO, FeO, \text{ and } MnO$. I have not seen the last slag in a glassy state. When it is required to reduce slags to powder, as is frequently the case, it follows from the preceding considerations that a simple and effectual way of rendering them as brittle as possible is to cool them with great rapidity by allowing them to flow into water.

COLOUR OF SLAGS.

With respect to *colour*, slags of common occurrence are grey, blue, green, red, brown, or black, of various shades. Occasionally the same slag is beautifully veined or marbled, with varying shades of colour; and an attempt has been made to apply such slags to ornamental purposes, though unsuccessfully. It is remarkable that the colour of a slag is sometimes entirely changed by crystallization; thus, a slag frequently produced in iron-smelting is blue in the vitreous and yellowish-brown in the crystallized state; and single specimens often exhibit both kinds of coloration. Specimens also may be picked up at bottle-glass works, each of which consists of brown crystallized nodular masses, embedded in a glassy blue matrix.

BLUE COLOUR.—The cause of the beautiful blue colour, which is not unfrequently seen in slags from iron-smelting furnaces, has excited much attention. It was ascribed to an oxide of titanium by Kersten, who also referred to the same oxide the blue coloration of the Silesian zinc-retorts, which is very similar to that of the slags in question. He found this oxide in the substance of which the retorts were made. He passed the vapour of zinc over titanous acid heated to redness, and the acid became blue. He then prepared mixtures of the ingredients of which slags are composed, and melted them; but the blue colour was not developed. When, however, they were kept melted at a strong heat in covered crucibles, with the addition of a little titanous acid and zinc, tin, or iron, they became blue. The

¹ Geology of the United States Exploring Expedition, p. 179.

specimens thus produced were inspected by Berzelius, who regarded the proof as conclusive.²

Fournet opposed the explanation of Kersten on the ground that certain slags, which were remarkable for the amount of titanium which they contained, were not blue, but grey in the interior and pale-yellow on the surface; and that other slags, in which there was no reason to suspect the presence of titanium, were blue. He observed, moreover, that when common green bottle-glass is kept heated during a sufficient length of time at a temperature considerably below its melting-point, it was rendered opaque and acquired a blue colour similar to that of the slags. I have also obtained the same result by experiment. Fournet had thin sections made of the glass so coloured, and found that when seen by transmitted light it had a greenish-yellow tint. D'Artigues had previously ascertained the same fact. Fournet showed that the powder of the blue slags and blue glass had only a dirty green tint. By melting a silicate of iron and alumina, Berthier obtained a glass which, by reflexion, presented a green, almost black tint, but which appeared resin-yellow by transmitted light.³ From these considerations Fournet inferred that the blue coloration, both of slags and bottle-glass, was entirely due to the same cause, namely, the same change in molecular arrangement which occasioned opacity in the bottle-glass.⁴

Bontemps, who has had great experience in the manufacture of glass, and especially in its coloration, attributes the greenish colour of bottle-glass to oxide of iron combined with carbonaceous matters contained in the mixture. When the temperature is not very high, as, for example, in the covered pots in which flint-glass is made, oxide of iron gives a *green* colour, more nearly approaching yellow than blue; but when the temperature is high, as in the manufacture of window-glass, the addition of a small proportion of oxide of iron to the mixture produces a glass of a *blueish* colour. He also remarks that it is known to the manufacturers of bottle-glass, that when the glass is cooled in the pot it becomes opaque *blue* before being devitrified. He concludes from actual observation that glass may acquire all the colours of the spectrum from oxide of iron alone; and that these colours are produced in their natural order in proportion as the temperature increases. Thus the manufacturers of china and earthenware obtain a *purplish-red* from sesquioxide of iron at a certain temperature; and at a higher temperature the same oxide yields an *orange* colour. These temperatures are low as compared with that at which glass is melted; and, as has been stated above, the oxide renders glass *green* at one temperature and *blue* at a higher temperature.⁵

The blue colour of slags has also been referred to vanadium⁶ and artificial ultramarine. With respect to vanadium, it may be true

² Berzelius' Jahresbericht, 1841, xx. (pt. 2) 97.

³ Traité des Essais, i. 448.

⁴ Ann. de Chim. et de Phys. s. 3, 1842, iv. 370.

⁵ Inquiries on some Modifications in the

Colouring of Glass by Metallic Oxides. By G. Bontemps. Phil. Mag. 1849, xxx. 439.

⁶ Kersten, Ann. des Mines, s. 4, 1842, ii. 483.

that certain blue slags contain this metal, but no satisfactory proof has been advanced that it is the cause of their blue colour; and, in respect to artificial ultramarine, upon which I have made numerous experiments, I have always found that its colour is destroyed at a temperature much below the fusing-point of the compound of silicate of soda and alumina, which constitutes its so-called base. On a review of the evidence, I incline to the belief that oxide of iron is the essential element of the blue colour of the slags.

DARK COLORATION OF SLAGS BY ALKALINE OR EARTHY SULPHIDES.—Slags from iron-smelting furnaces have occasionally a very dark colour in mass, which might lead to the supposition that they contain a large proportion of iron. Analysis, however, has proved, as will be shown in the sequel, that this is not necessarily the case. It seems not improbable that this deep colour may in some cases be due to sulphur. In the French department of the Great Exhibition of 1851 were exhibited some vessels of glass remarkable for their intensely black colour, which Dumas assured me was produced entirely by the addition of sulphur. Berthier obtained a red glass of silicate of soda, the colour of which he supposed to be due to sulphide of sodium.⁷ It is well known that the addition of carbonaceous matter to ordinary molten white window-glass colours it yellow; but this effect is not, as was supposed, due to the presence of finely divided carbon, and does not occur when glass perfectly free from sulphates is the subject of treatment. The colour depends upon the formation of alkaline or earthy sulphides, by the deoxidizing action of the carbonaceous matter upon alkaline or earthy sulphates existing in the glass. Other reducing agents, such as silicon, boron, and hydrogen, produce the same kind of coloration in glass as carbonaceous matter; and so does the direct addition of sulphur, selenium, an alkaline or earthy sulphide or phosphide, but not phosphorus.⁸ If a piece of common glass is heated to redness and then cooled in a current of hydrogen, it acquires a faint yet sensibly yellow tint; and if powder of the glass is subjected to the same treatment, the formation of alkaline sulphide may be clearly demonstrated. By fusing a mixture of 250 grammes of white sand, 100 of soda (containing 90 per cent. of pure soda), and 50 of carbonate of lime, with the addition of 40 of sulphide of calcium (i.e. 10 per cent.), Pelouze obtained a very dark-coloured scarcely transparent glass; with the same mixture, but only 2·5 per cent. of the sulphide, a much yellower glass was produced than he anticipated; and with the addition of only 1·25 per cent. of the sulphide, the same mixture yielded a colourless glass. According to Splitgerber, when a piece of glass of about 4 millimetres (0·16 of an inch) thick, and coloured brown-yellow by sulphide of sodium, is exposed during 10 or 15 minutes to a gentle red-heat, insufficient to cause softening, it becomes darker coloured and less transparent, and by prolonged exposure to this temperature it is rendered quite opaque.

⁷ *Traité des Essais*, i. 425.

⁸ C. Splitgerber, *Wagner's Jahresbericht*, 1856, i. 154; Pelouze, *Comptes*

rendus, 1865, lx. 985, and *Wagner's Jahresbericht*, 1865, xi. 422.

If now this opaque glass is more strongly heated, so as to round off its edges and bend it, the original transparency and colour are restored. On reheating it, as in the first instance, it again undergoes the same changes as those above described. These phenomena are explained by Splitgerber, on the supposition that changes are effected in the sulphide at the lower and higher temperatures analogous to those which sulphur itself suffers at such temperatures, when it is converted into the red and black modifications respectively. When the glass is transparent and bright yellow, it is inferred that the sulphide then exists in it in a state of solution, and that gradually becoming insoluble by prolonged exposure to the lower temperature, it finally separates and causes opacity. On reheating the glass, which has been so darkened in colour and rendered opaque, to the temperature of incipient fusion, the separated sulphide will re-dissolve in the mass and pass into its original yellow modification. A brown yellow glass which showed the changes above described was found by Splitgerber to contain about $\frac{1}{3}$ per cent. of sulphur, and to have the following composition :—

| COMPOSITION OF GLASS COLOURED BY SULPHIDE. | |
|--|--------------|
| Silica | 62.43 |
| Lime | 9.46 |
| Alumina, sesquioxide of iron, and peroxide of manganese..... | 1.72 |
| Potash | 26.04 |
| Sulphur | 0.35 |
| | <hr/> 100.00 |

IRIDESCENCE.—Slags are occasionally met with which present exquisitely beautiful iridescence, quite equal to that so highly prized in certain kinds of pottery. In some, consisting chiefly of silicate of protoxide of iron, crystals of the silicate are imbedded, which are marked with coloured bands of great distinctness and beauty. In my collection I have many illustrations of this kind.

FUSIBILITY OF SLAGS.

This is a subject of great practical importance. When melted, some slags are as liquid as water, and others are in a greater or less degree viscous. A particular degree of consistency may be essential to the success of a process in which the slag is separated by skimming from subjacent metalliferous matter such as regulus: if too thin, metalliferous matter is liable to be drawn out of the furnace along with the slag; and if too thick, it may not have properly subsided. In all cases in which the ores of such metals as copper, tin, etc., are smelted, the slags should be carefully inspected in order to ascertain that shots of regulus or metal are not retained in them. A slag is said to be *clean* or *not clean*, according as it is free or not free from any

sensible quantity of the metallic matter which is the object of extraction, whether present in a state of chemical combination, solution, or mechanical diffusion.

ACTION OF HEAT ON MIXTURES OF SILICA AND VARIOUS BASES.

The following information on the fusibility of silicates has been mainly derived from the experiments of Berthier, and to a limited extent from those of Sefström, the distinguished Swedish metallurgist, and of the Author and his Assistant at the Royal School of Mines. Lampadius, it should also be stated, published at the end of the last century the results of numerous experiments by himself on the same subject.* The formulæ in the following table merely indicate the proportions of the ingredients in the mixtures operated upon, and must not be supposed to represent in all cases definite chemical compounds of which the existence has been established.

It must be borne in mind that Berthier's work (*Traité des Essais par la voie sèche*) was published in 1834, and that the equivalent weights which he employed were those adopted by Berzelius at the time.

TABLE OF REFERENCE NUMBERS AND COMPOSITION OF MIXTURES.

| No. | FORMULA. Old Notation. | Composition per Cent. | | | FORMULA. New Notation. |
|-----|-------------------------------|-----------------------|--------|----|---|
| | | Silica. | Bases. | | |
| 1 | KO, SiO ³ | 49·5 | 50·5 | .. | 2K ² O, 3SiO ² . |
| 2 | KO, 2SiO ³ | 66·2 | 33·8 | .. | K ² O, 3SiO ² . |
| 3 | KO, 3SiO ³ | 74·6 | 25·4 | .. | 2K ² O, 9SiO ² . |
| 4 | KO, 4SiO ³ | 79·7 | 20·3 | .. | K ² O, 6SiO ² . |
| 5 | KO, 6SiO ³ | 85·7 | 14·3 | .. | K ² O, 9SiO ² . |
| 6 | KO, 10SiO ³ | 91·0 | 9·0 | .. | K ² O, 15SiO ² . |
| 7 | NaO, SiO ³ | 59·8 | 40·2 | .. | 2Na ² O, 3SiO ² . |
| 8 | NaO, 2SiO ³ | 74·8 | 25·2 | .. | Na ² O, 3SiO ² . |
| 9 | NaO, 3SiO ³ | 81·7 | 18·3 | .. | 2Na ² O, 9SiO ² . |
| 10 | NaO, 4SiO ³ | 85·6 | 14·4 | .. | Na ² O, 6SiO ² . |
| 11 | NaO, 6SiO ³ | 90·1 | 9·9 | .. | Na ² O, 9SiO ² . |
| 12 | NaO, 8SiO ³ | 92·4 | 7·6 | .. | Na ² O, 12SiO ² . |
| 13 | NaO, 10SiO ³ | 93·8 | 6·2 | .. | Na ² O, 15SiO ² . |
| 14 | 3BaO, SiO ³ | 17·2 | 82·3 | .. | 2BaO, SiO ² . |
| 15 | 3BaO, 2SiO ³ | 29·3 | 70·7 | .. | BaO, SiO ² . |
| 16 | BaO, SiO ³ | 38·4 | 61·6 | .. | 2BaO, 3SiO ² . |
| 17 | BaO, 2SiO ³ | 55·5 | 44·5 | .. | BaO, 3SiO ² . |
| 18 | BaO, 3SiO ³ | 65·2 | 34·8 | .. | 2BaO, 9SiO ² . |
| 19 | BaO, 4SiO ³ | 71·5 | 28·5 | .. | BaO, 6SiO ² . |
| 20 | 3SrO, 4SiO ³ | 55·1 | 44·9 | .. | SrO, 2SiO ² . |
| 21 | SrO, 3SiO ³ | 73·4 | 26·5 | .. | 2SrO, 9SiO ² . |
| 22 | 12CaO, SiO ³ | 11·5 | 88·5 | .. | 8CaO, SiO ² . |
| 23 | 6CaO, SiO ³ | 22·0 | 78·0 | .. | 4CaO, SiO ² . |
| 24 | 4CaO, SiO ³ | 29·7 | 70·3 | .. | 8CaO, 3SiO ² . |
| 24a | 9CaO, 2SiO ³ | 26·75 | 73·25 | .. | 3CaO, SiO ² . |
| 25 | 3CaO, SiO ³ | 35·8 | 64·2 | .. | 2CaO, SiO ² . |
| 25a | 2CaO, SiO ³ | 45·1 | 54·9 | .. | 4CaO, 3SiO ² . |
| 25b | 9CaO, 4SiO ³ | 42·21 | 57·79 | .. | 3CaO, 2SiO ² . |
| 26 | 3CaO, 2SiO ³ | 52·8 | 47·2 | .. | CaO, SiO ² . |

* Journal des Mines, xviii. 171 *et seq.*; translation of Handbuch der allgemeinen Hüttenkunde by Lampadius, i. 127; 1798-1800.

TABLE OF REFERENCE NUMBERS AND COMPOSITION OF MIXTURES—continued.

| No. | FORMULA. Old Notation. | Composition per Cent. | | | FORMULA. New Notation. |
|-----|---|-----------------------|--------|-------|---|
| | | Silica. | Bases. | | |
| 27 | CaO,SiO ³ | 62.2 | 37.8 | .. | 2CaO,3SiO ² . |
| 27a | CaO,2SiO ³ | 76.42 | 23.58 | .. | CaO,3SiO ² . |
| 28 | 3CaO,4SiO ³ | 75.6 | 24.4 | .. | CaO,2SiO ² . |
| 29 | 6MgO,SiO ³ | 27.8 | 72.2 | .. | 4MgO,SiO ² . |
| 29a | 9MgO,2SiO ³ | 32.75 | 67.25 | .. | 3MgO,SiO ² . |
| 30 | 3MgO,SiO ³ | 43.5 | 56.5 | .. | 2MgO,SiO ² . |
| 30a | 2MgO,SiO ³ | 52.28 | 47.72 | .. | 4MgO,3SiO ² . |
| 31 | 3MgO,2SiO ³ | 59.9 | 40.1 | .. | MgO,SiO ² . |
| 31a | 9MgO,4SiO ³ | 49.33 | 50.67 | .. | 3MgO,2SiO ² . |
| 32 | MgO,SiO ³ | 70.0 | 30.0 | .. | 2MgO,3SiO ² . |
| 33 | 2Al ² O ³ ,SiO ³ | 35.7 | 64.3 | .. | 4Al ² O ³ ,3SiO ² . |
| 34 | Al ² O ³ ,SiO ³ | 47.4 | 52.6 | .. | 2Al ² O ³ ,3SiO ² . |
| 35 | Al ² O ³ ,2SiO ³ | 64.3 | 35.7 | .. | Al ² O ³ ,3SiO ² . |
| 36 | Al ² O ³ ,3SiO ³ | 73.0 | 27.0 | .. | 2Al ² O ³ ,9SiO ² . |
| 37 | KO,NaO,10SiO ³ | 85.5 | 8.7 | 5.8 | K ² O,Na ² O,15SiO ² . |
| 38 | KO,NaO,20SiO ³ | 92.4 | 4.7 | 2.9 | K ² O,Na ² O,30SiO ² . |
| 39 | KO,Al ² O ³ ,4SiO ³ | 65.94 | 16.31 | 17.75 | K ² O,Al ² O ³ ,6SiO ² . |
| 40 | NaO,Al ² O ³ ,4SiO ³ | 69.72 | 11.43 | 18.79 | Na ² O,Al ² O ³ ,6SiO ² . |
| 41 | 3KO,5Al ² O ³ ,22SiO ³ | 73.0 | 8.4 | 16.2 | 3K ² O,5Al ² O ³ ,33SiO ² . |
| 42 | BaO,11CaO,8SiO ³ | 48.6 | 10.0 | 41.4 | BaO,11CaO,12SiO ² . |
| 43 | BaO,5CaO,8SiO ³ | 63.1 | 24.8 | 12.1 | BaO,5CaO,12SiO ² . |
| 44 | 3BaO,6Al ² O ³ ,14SiO ³ | 55.0 | 19.0 | 26.0 | BaO,2Al ² O ³ ,7SiO ² . |
| 45 | 3BaO,4Al ² O ³ ,12SiO ³ | 57.0 | 22.7 | 20.3 | 3BaO,4Al ² O ³ ,18SiO ² . |
| 46 | 3CaO,3MgO,2SiO ³ | 39.0 | 35.5 | 25.5 | CaO,MgO,SiO ² . |
| 47 | 3CaO,3MgO,4SiO ³ | 56.4 | 25.3 | 18.3 | CaO,MgO,2SiO ² . |
| 48 | CaO,2MgO,2SiO ³ | 57.5 | 17.3 | 25.2 | CaO,2MgO,3SiO ² . |
| 49 | 2CaO,MgO,2SiO ³ | 54.4 | 33.5 | 12.1 | 2CaO,MgO,3SiO ² . |
| 50 | CaO,3MgO,3SiO ³ | 70.4 | 9.3 | 20.3 | 2CaO,6MgO,9SiO ² . |
| 51 | CaO,MgO,2SiO ³ | 66.2 | 19.8 | 14.0 | CaO,MgO,3SiO ² . |
| 52 | 2CaO,MgO,4SiO ³ | 71.1 | 21.2 | 7.7 | 2CaO,MgO,6SiO ² . |
| 53 | CaO,2MgO,4SiO ³ | 73.3 | 10.9 | 15.8 | CaO,2MgO,6SiO ² . |
| 54 | 3CaO,Al ² O ³ ,SiO ³ | 25.9 | 46.3 | 27.8 | 6CaO,2Al ² O ³ ,3SiO ² . |
| 55 | 3CaO,Al ² O ³ ,2SiO ³ | 41.0 | 36.8 | 22.0 | 3CaO,Al ² O ³ ,3SiO ² . |
| 56 | 3CaO,Al ² O ³ ,4SiO ³ | 58.2 | 26.1 | 15.7 | 3CaO,Al ² O ³ ,6SiO ² . |
| 57 | 3CaO,Al ² O ³ ,6SiO ³ | 67.7 | 20.2 | 12.1 | 3CaO,Al ² O ³ ,9SiO ² . |
| 58 | 3CaO,2Al ² O ³ ,3SiO ³ | 43.7 | 26.0 | 31.8 | 6CaO,4Al ² O ³ ,9SiO ² . |
| 58a | 3CaO,2Al ² O ³ ,4SiO ³ | 49.25 | 22.80 | 27.95 | 3CaO,2Al ² O ³ ,6SiO ² . |
| 58b | 3CaO,2Al ² O ³ ,6SiO ³ | 59.28 | 18.29 | 22.43 | 3CaO,2Al ² O ³ ,9SiO ² . |
| 59 | 3CaO,3Al ² O ³ ,4SiO ³ | 44.3 | 19.9 | 35.8 | CaO,Al ² O ³ ,2SiO ² . |
| 60 | CaO,Al ² O ³ ,4SiO ³ | 70.5 | 10.5 | 19.0 | CaO,Al ² O ³ ,6SiO ² . |
| 61 | 6CaO,Al ² O ³ ,3SiO ³ | 38.4 | 47.3 | 14.2 | 12CaO,2Al ² O ³ ,9SiO ² . |
| 62 | .. .. | 26.5 | 60.0 | 13.5 | .. .. |
| 63 | .. .. | 31.2 | 52.8 | 16.0 | .. .. |
| 64 | .. .. | 34.1 | 48.3 | 17.6 | .. .. |
| 65 | .. .. | 33.3 | 60.0 | 6.7 | .. .. |
| 66 | 3MgO,Al ² O ³ ,2SiO ³ | 45.9 | 29.3 | 24.8 | 3MgO,Al ² O ³ ,3SiO ² . |
| 67 | 3MgO,Al ² O ³ ,4SiO ³ | 63.0 | 20.0 | 17.0 | 3MgO,Al ² O ³ ,6SiO ² . |
| 68 | 6FeO,SiO ³ | 18.0 | 82.0 | .. | 4FeO,SiO ² . |
| 69 | 3FeO,SiO ³ | 31.0 | 69.0 | .. | 2FeO,SiO ² . |
| 70 | 3FeO,2SiO ³ | 47.5 | 52.5 | .. | FeO,SiO ² . |
| 71 | FeO,SiO ³ | 57.5 | 42.5 | .. | 2FeO,3SiO ² . |
| 72 | Fe ² O ³ ,SiO ³ | 37.7 | 62.3 | .. | 2Fe ² O ³ ,3SiO ² . |
| 73 | Fe ² O ³ ,2SiO ³ | 54.7 | 45.3 | .. | Fe ² O ³ ,3SiO ² . |
| 74 | 3FeO,3CaO,2SiO ³ | 33.7 | 36.4 | 29.9 | FeO,CaO,SiO ² . |
| 75 | 2FeO,CaO,SiO ³ | 32.9 | 47.5 | 19.6 | 4FeO,2CaO,3SiO ² . |
| 76 | 3FeO,3CaO,4SiO ³ | 50.0 | 28.0 | 22.0 | FeO,CaO,2SiO ² . |
| 77 | 3FeO,12MgO,5SiO ³ | 40.3 | 17.5 | 42.2 | 2FeO,8MgO,5SiO ² . |
| 78 | 3FeO,Al ² O ³ ,2SiO ³ | 37.6 | 42.0 | 20.4 | 3FeO,Al ² O ³ ,3SiO ² . |
| 79 | Fe ² O ³ ,3CaO,2SiO ³ | 36.1 | 30.6 | 33.3 | Fe ² O ³ ,3CaO,3SiO ² . |
| 80 | Fe ² O ³ ,Al ² O ³ ,2SiO ³ | 35.7 | 38.8 | 25.5 | Fe ² O ³ ,Al ² O ³ ,3SiO ² . |
| 81 | Fe ² O ³ ,Al ² O ³ ,4SiO ³ | 60.0 | 24.0 | 16.0 | Fe ² O ³ ,Al ² O ³ ,6SiO ² . |

TABLE OF REFERENCE NUMBERS AND COMPOSITION OF MIXTURES—continued.

| No. | FORMULA. | Composition per Cent. | | | FORMULA. |
|-----|--|-----------------------|--------|------|---|
| | Old Notation. | Silica. | Bases. | | New Notation. |
| 82 | 6MnO,SiO ³ | 18.0 | 82.0 | .. | 4MnO,SiO ² . |
| 83 | 3MnO,SiO ³ | 33.8 | 66.2 | .. | 2MnO,SiO ² . |
| 84 | 3MnO,2SiO ³ | 46.6 | 53.4 | .. | MnO,SiO ² . |
| 85 | 3MnO,4SiO ³ | 64.0 | 36.0 | .. | MnO,2SiO ² . |
| 86 | 3MnO,3CaO,4SiO ³ ... | 49.7 | 26.7 | 23.6 | MnO,CaO,2SiO ² . |
| 87 | MnO,2CaO,2SiO ³ | 49.8 | 19.6 | 30.6 | MnO,2CaO,3SiO ² . |
| 88 | 4MnO,4CaO,6SiO ³ | 52.4 | 26.8 | 20.8 | 4MnO,4CaO,9SiO ² . |
| 89 | MnO,2CaO,3SiO ³ | 60.5 | 15.5 | 24.0 | MnO,2CaO,3SiO ² . |
| 90 | 3MnO,12CaO,22SiO ³ | 70.6 | 7.1 | 22.3 | MnO,4CaO,11SiO ² . |
| 91 | 3MnO,3MgO,2SiO ³ ... | 36.1 | 41.2 | 22.7 | MnO,MgO,SiO ² . |
| 92 | 3MnO,3MgO,4SiO ³ ... | 52.6 | 30.4 | 17.0 | MnO,MgO,2SiO ² . |
| 93 | 2MnO,MgO,2SiO ³ | 48.9 | 40.0 | 11.1 | 2MnO,MgO,3SiO ² . |
| 94 | 3MnO,2Al ¹ O ³ ,4SiO ³ .. | 46.7 | 27.5 | 25.8 | 3MnO,2Al ¹ O ³ ,6SiO ² . |
| 95 | ..... | 57.0 | 19.0 | 23.8 | ..... |
| 96 | 3FeO,3MnO,4SiO ³ | 47.0 | 27.0 | 26.0 | FeO,MnO,2SiO ² . |

MODE OF EXPERIMENTING, AND DESCRIPTION OF THE PRODUCTS.

B. Abbreviation for Berthier.

P. S. " Percy and Smith.

(G. f) " Grand feu, air-furnace capable of producing 150° pyrometer of Wedgwood (p. being the abbreviation for this pyrometer) in two hours. A description of this instrument will be given in the sequel, in the article on Pyrometers. (See p. 174.)

(S.) " porcelain-furnace at Sèvres, which Berthier estimates at 140° p.

When, in recording Berthier's experiments, no mention is made of the furnace used, it is to be understood that he employed a portable air-furnace of fire-clay, having a sheet-iron chimney 1 metre high, and that charcoal was the fuel. The temperature capable of being attained in such a furnace was from 50° to 60° p. The language, in which Berthier described his products, has for the most part been literally translated.

Experiments were made some years ago by the Author and his Assistant, R. Smith, on the fusibility of various mixtures of silica with lime, and silica with magnesia. Generally, black-lead crucibles lined with anthracite powder mixed with tarry matter were employed, as clay crucibles were found to be so rapidly attacked that no certain results could be obtained with them. (In Berthier's experiments, described in the present article, crucibles lined with carbon were also used.) The silica was in the state of fine white sand, such as is used by glass-makers. The lime was prepared from Carrara marble, slaked and re-heated so as to expel the water of hydration: it was thus obtained in a state of very fine division. The magnesia was prepared by calcination of the carbonate. The ingredients were well mixed by trituration in a mortar. The furnace employed, when

not otherwise stated, was an air-furnace having a stack somewhat exceeding 60 feet in height; the fuel was anthracite; and a temperature sufficient to melt manganese could easily be obtained in this furnace.

Sefström's experiments were limited to the action of high temperatures on certain mixtures of silica with lime, magnesia, and alumina. These experiments were made by the students of the School of Mines at Fahlun, in Sweden, under the direction of Sefström. The mixtures were heated, in crucibles lined with charcoal, in a Sefström's blast-furnace, in which wrought-iron, manganese, and pure nickel could be melted.¹ A description of this furnace will be found further on in this volume.

NOTE.—I have ventured to use in the following descriptions four words taken from the French which are not admitted as English, namely *lamellar*, *bubbly*, *pulverulent*, and *metalloid*, and I have done so because they are convenient, and, so far as I know, have no exact synonyms in English. *Lamellar* is derived from the technical word *lamellaire*, which in the Dictionary of the Academy (1854) is stated to apply to "a mineral of which the fracture presents brilliant facets suggestive of a confused mass of plates." *Bubbly*—this is certainly an ugly word, yet very expressive—it is derived from *bulleux*, which means, containing bubbles of air. *Pulverulent* is taken from *pulvérulent*, which means, in the state of powder. *Metalloid* is derived from *metalloïde*, which means, approaching metallic.

1, 2, 3, 4. Transparent glass, more or less bubbly. At 50° p. 3 parts of carbonate of potash or soda form a very liquid compound with silica; at 150° p. only a very small quantity of alkali is sufficient to produce this effect. B.

5. Transparent colourless glass, but very full of bubbles. B.

6. Transparent glass, but scoriaceous, occupying the same volume as the original silica. B.

7, 8, 9, 10. Transparent glass, compact, or more or less bubbly. B.

11, 12. Transparent glass, but very full of bubbles. B.

13. Enamel-like, white, scoriform, slightly translucent, occupying the same volume as the materials employed. B.

14. (G. f.) and (S.) Agglomeration and commencement of pasty fusion. B.

15. (S.) Button compact, a little bubbly on the surface, fracture scaly and waxy. B.

16. (S.) Button free from bubbles, tender, fracture crystalline, fragments translucent, shining. B.

17, 18. (S.) Compact, translucent, fracture conchoidal, slightly waxy. B.

19. (G. f.) Enamel-like, white, porous, hard, opaque or slightly translucent; imperfect fusion. B. These silicates were prepared with sand and native carbonate of baryta.

20. (G. f.) Enamel-like, white, compact, free from bubbles, transparent in some parts, but throughout hardly translucent at the edges, fracture slightly conchoidal, shining. B.

¹ Extracted from Erdmann's Journal für technische und ökonomische Chemie, 1831, x. 135; translated from the Jern-Kontoret's Annaler of 1828.

21. (G. f.) Slightly enamel-like, scoriform, full of cavities like a sponge, slightly translucent; no fusion. B. These silicates were prepared with sand and artificial carbonate of strontia.

22, 23, 24. Pulverulent. B.

23. Mixture of 896 grains of lime and 245 grains of silica. Per cent., lime 78.50, and silica 21.50. Exposed to a white-heat during an hour and a half; not melted. *Experiment repeated.* Exposed to a white-heat during two hours; not melted. P. S.

24a. Mixture of 756 grains of lime and 276 grains of silica. Per cent., lime 73.25, and silica 26.75. Exposed to a white-heat during an hour and a half; not melted. *Experiment repeated.* Exposed to a white-heat during two hours; not melted. *Experiment repeated.* Exposed to a white-heat during two hours; not melted. P. S.

25. Partly scoriform and partly pulverulent; incipient fusion. B.

The mixture could not be melted. An experiment was then made to ascertain whether the silicate $3\text{CaO}, 2\text{SiO}_3$ [CaO, SiO_2] (No. 26) would combine with more lime. Pieces of this silicate were placed in carbonate of lime and exposed to as much heat as the crucible could support. On opening the crucible the whole mass appeared to be sintered together, but on taking it out, it immediately fell to pieces; only the internal part, where the silicate lay, remained entire, the other part of the mass being in the state of white powder. The solid nucleus remained in a coherent state during twenty-four hours, but it became disintegrated when moistened with water, and sometimes with the evolution of heat. Other experiments were next made by heating the silicate with less lime, and in one case the product was actually melted; but when it was taken hot out of the furnace it fell to pieces in less than a minute afterwards. By allowing the mass to cool in the crucible, it remained in a coherent state during several days. This product was analysed, and found to consist of 41.10 per cent. of silica and 58.77 of lime. It might, consequently, be regarded as a mixture of two silicates of the respective formulæ, $3\text{CaO}, 2\text{SiO}_3$ and $3\text{CaO}, \text{SiO}_3$ [CaO, SiO_2 and $2\text{CaO}, \text{SiO}_2$]. Sesquibasic silicate of protoxide of iron, $3\text{FeO}, 2\text{SiO}_3$ [FeO, SiO_2], was mixed with sufficient caustic lime to form the silicate of lime, $3\text{CaO}, \text{SiO}_3$ [$2\text{CaO}, \text{SiO}_2$], after reduction of the protoxide of iron. After an hour's firing there was produced a tender mass of a grey spongy glass, which dissolved in hydrochloric acid with the evolution of hydrogen—but not of carbonic acid—and the separation of gelatinous silica. Distinct metallic particles were not perceived until after repeatedly melting the mass at a still higher temperature. The proportion of silica was next increased, so that equal parts of the silicates $3\text{CaO}, \text{SiO}_3$ and $3\text{CaO}, 2\text{SiO}_3$ [$2\text{CaO}, \text{SiO}_2$ and CaO, SiO_2], might be formed. After an hour and a half's firing, a little finely foliated cast-iron and a well-melted product were obtained, but the latter immediately fell to powder. The last experiment was repeated with a sustained blast during two hours. A button of grey fine-grained cast-iron was produced, and a well-melted glassy product, which no longer crumbled to powder. Sefström.

Mixture of 1260 grains of lime and 690 grains of silica. Per

cent., lime 64·60, and silica 35·40.—Exposed to a white-heat during three hours; not melted. Some gelatinous silica was separated by the action of hydrochloric acid. Re-heated during an hour in Sefström's blast-furnace. Still not melted, but some dark-grey melted particles were found in the mixture near the bottom of the crucible. A portion of this mixture was again exposed to a white-heat during three hours; not melted. *Experiment repeated* with 840 of lime and 460 of silica. Exposed to a strong white-heat during two hours; not melted. *Experiment repeated*. Exposed to a white-heat during four hours and a half; not melted. *Experiment repeated*. Exposed to a white-heat during three hours; not melted. P. S.

25a. Mixture of 560 grains of lime and 460 grains of silica. Per cent., lime 54·90, and silica 45·10.—Exposed to a white-heat during two hours; melted. Compact and slightly crystalline. *Experiment repeated* with 840 of lime and 690 of silica. Exposed to a white-heat during four hours and a half. About one-sixth of the mixture near the bottom was melted; fracture crystalline. P. S.

25b. Mixture of 1008 grains of lime and 736 grains of silica. Per cent., lime 57·79, and silica 42·21.—Exposed to a white-heat during an hour and a quarter; partly melted into lumps, which contained cavities lined with small imperfect crystals. *Experiment repeated* with 756 of lime and 552 of silica. Exposed to a white-heat during two hours. A small portion near the bottom melted into a compact glassy mass; the rest not melted. *Experiment repeated* with the same quantities. Exposed to a white-heat during four hours and a half; not melted. *Experiment repeated* with the same quantities. Exposed to a white-heat during two hours and a half; not melted. Mixture adhered together, but crumbled under very slight pressure. *Experiment repeated*. Exposed to a white-heat during two hours and a half; about one-third melted at the bottom. Compact, with crystalline fracture. P. S.

26. (S.) Slightly bubbly, aspect stony, fracture granular; in cavities brilliant, distinct but very small crystals were observed. B. (G.f.) Scoriform and half-glassy after an hour's heating; heated during two hours, partly compact and partly bubbly, translucent, fracture waxy, slightly shining. B. This has the same formula as *tabular spar* or *wollastonite*.

Mixture of 1260 grains of lime and 1380 grains of silica. Per cent., lime 47·72, and silica 52·28.—Exposed to a white-heat during two hours and a half; well-melted; compact, with a few large cavities in the centre; fracture glassy, lower part slightly crystalline. *Experiment repeated* in a Cornish crucible. Exposed to a white-heat during two hours. The mixture formed a fused mass with the crucible. *Experiment repeated* in a Cornish crucible, enclosed in another of the same kind. Exposed to a white-heat during two hours and a half. The outer crucible was only a little acted upon, but the inner one was melted into a clear glass with the mixture. *Experiment repeated* in a black-lead crucible with 840 of lime and 920 of silica. Exposed to a white-heat during four hours and a half; melted.

The upper part contained large cavities lined with imperfectly defined crystals; lower part compact with a crystalline fracture. *Experiment repeated* with the same quantities. Exposed to a white-heat during an hour; melted; crystallized in thin plates running in various directions; the transverse fracture presented the appearance of fibrous crystals radiating from the centre and intersecting each other at numerous points. *Experiment repeated* in a platinum crucible with 252 of lime and 276 of silica. Exposed to a white-heat during about an hour; well-melted, but with cavities; opaque, greyish-white; shining tabular crystals lining the cavities and on the surface at the top. P. S.

Pure white marble and white quartz were employed. Seven experiments are recorded, in all of which the product was well-melted after an hour's blast. Both externally and on the fractured surface there were decided signs of crystallization. The fracture was alternately crystalline, splintery, or glassy. The thin edges of pieces were slightly transparent. The colour was more or less blue-grey, occasionally passing into sea-green. In most cases the product resembled the common blue agates of which mortars are made. They all had an iron-grey coating, which was not attacked by hydrochloric acid, and which, therefore, could not be due to iron derived from the carbon crucible employed. By exposure to a red-heat in an open crucible this film disappeared, but it came again on remelting the product, during which there was so little loss that 6 grms. were only reduced to 5.997 grms. The average specific gravity of the product obtained in five experiments was 2.861, the extremes being 2.781 and 2.893. Sefström.

27. (S.) Button scoriform, beautiful white, translucent, resembling porcelain; fracture uneven, finely granular; scratched glass. B.

This silicate generally melts far more easily than the last, so that if both are placed in the furnace at the same time it will be perfectly melted when the other is only just fritted. The two silicates so closely resemble each other that they cannot be distinguished in external appearance. This silicate seems to be somewhat more brittle than the last. The results of five experiments are recorded, and the average specific gravity of the products obtained was 2.744, the extremes being 2.731 and 2.755. Sefström.

Mixture of 840 grains of lime and 1389 grains of silica. Per cent., lime 37.83, and silica 62.17.—Exposed to a white-heat during an hour and twenty minutes; about two-thirds melted into a compact glassy mass, the upper part containing small cavities lined with little crystals; top of the mixture not melted. *Experiment repeated*. Exposed to a white-heat during two hours and a half; not melted. The same mixture was further exposed to a white-heat during five hours; about half the mixture melted into a porous crystalline mass; the rest not melted, but adhered together. *Experiment repeated*. Exposed to a white-heat during three hours; not melted. The same mixture was further exposed to a white-heat during two hours and three quarters; well-melted. Compact, with a few small cavities near the surface. P. S.

27a. This silicate is not given by Berthier. A melted mass was obtained, which, nevertheless, appeared to be homogeneous, especially when cut. Its colour was pearl-grey, passing into blue. Sefström.

28. (S.) Scoriform, translucent, without solidity, gritty between the fingers. (G. f.) Transparent porous glass. B.

The mixture became fluid in a certain degree and appeared to separate into two layers, of which the lower one was darker and more compact, and resembled CaO, SiO_2 [$2\text{CaO}, 3\text{SiO}_2$], while the upper one, on the contrary, had a light and spongy aspect. The lower layer was found to be composed of 64·97 of silica and 35·52 of lime. Sefström.

29, 30. (S.) Compact, with but little tenacity, easily crushed, yet hard enough to scratch glass; fracture uneven, granular, dull; although there was no softening, yet combination took place, as gelatinous silica was separated by acids. B.

29. Mixture of 756 grains of magnesia and 276 grains of silica. Per cent., magnesia 73·25, and silica 26·75.—Exposed to a white-heat during two hours; not melted, but fritted. P. S.

29a. Mixture of 756 grains of magnesia and 368 grains of silica. Per cent., magnesia 67·25, and silica 32·75.—Exposed to a white-heat during two hours; melted. Largely porous. P. S.

30. The product was a milk-white, glassy, porous mass. Sefström.

Mixture of 756 grains of magnesia and 552 grains of silica. Per cent., magnesia 57·79, and silica 42·21.—Exposed to a white-heat during two hours; imperfectly fused into a white, hard, porous, slightly crystalline mass. P. S.

30a. Mixture of 756 grains of magnesia and 828 grains of silica. Per cent., magnesia 47·72, and silica 52·28.—Exposed to a white-heat during two hours; melted. Compact, with a few cavities in the centre; fracture crystalline. P. S.

31. (G. f.) Strongly agglomerated, stony, very hard, slightly porous, fracture granular, almost smooth; softening without fusion. B.

The product was a well-melted, pearl-coloured, almost white enamel, which was crystalline externally. It seemed to melt more readily than Nos. 30 and 32. Sefström.

Mixture of 756 grains of magnesia and 1104 grains of silica. Per cent., magnesia 40·64, and silica 59·36.—Exposed to a white-heat during an hour; about one-sixth of the mixture near the bottom was melted into a hard crystalline mass; the rest consisted of a partially melted, hard, slightly crystalline mass, passing into a *frit* near the top—that is, a mass more or less sintered or fritted together. The crucible, with its contents, was again exposed to a white-heat during an hour; the portion previously unmelted was now melted, yet not so completely as the portion first melted, of which the pieces could be readily recognised. P. S.

31a. Mixture of 756 grains of magnesia and 736 grains of silica. Per cent., magnesia 50·67, and silica 49·33.—Exposed to a white-heat during two hours; melted. Hard, porous, with traces of crystallization. P. S.

32. (S.) Button solid, tenacious, scratched glass; fracture compact, stony, dull; full of round cavities; incipient fusion. B.

Product similar to No. 31; more crystalline, but not so well melted. Sefström.

Mixture of 756 grains of magnesia and 1656 grains of silica. Per cent., magnesia 31·34, and silica 68·66.—Exposed to a white-heat during two hours; melted. Hard, porous, slightly crystalline. P. S.

33, 34. (S.) Agglomerated. B.

35. (S.) Strongly agglomerated, compact; fracture stony, dull. B.

36. (G. f.) Compact; fracture stony, slightly shining. B. These silicates of alumina were prepared with sand and calcined sulphate of alumina.

37. Glass, homogeneous, transparent, bubbly in places. B.

38. Glass, homogeneous, transparent, and penetrated throughout with a multitude of minute bubbles. B.

39, 40. (S.) and (G. f.) Transparent glass, always filled with a multitude of minute bubbles. No. 39 is feldspar—*orthoclase*. No. 40 is also feldspar—*oligoclase*. B.

41. (S.) This is the glaze used for porcelain at Sèvres; it melts on the biscuit into a colourless vitreous enamel; in a crucible lined with charcoal it melts into a glass containing large bubbles. B.

42. (G. f.) Compact, free from bubbles, transparent, fracture lamellar in one direction, but in other directions uneven and scaly. B.

43. (G. f.) Compact, free from bubbles, translucent, fracture largely conchoidal, brilliant, resembling beautiful chalcedony. B.

44, 45. (S.) Compact, free from bubbles; fracture even and shining, vitreous in places, presenting no indication of crystallization. No. 44 is identical with *harmotome*. B.

46. (S.) Compact, with a fine scaly close grain; thin fragments translucent. B.

This was prepared by heating a mixture of $3\text{CaO}, 2\text{SiO}_3$ [CaO, SiO_2] and magnesia. The product was a well-melted light blue-green glass having a granular fracture. Sefström.

47. (S.) Melts easily into a compact lamellar mass, with large plates or long prismatic fibres; the surface covered with polyhedral asperities, which are only the summits of the fascicular prisms of which it is composed. In several experiments the button contained a cavity lined with beautiful transparent crystals several millimetres broad. The button is sometimes saccharoidal instead of lamellar, but never vitreous. This is identical with *augite* or *pyroxene*. B. When melted with 6 per cent. of fluor-spar in powder, a button was obtained composed of large interlacing crystals, having spaces between them. The crystals were transparent or translucent, slightly greenish, brilliant, from 2 to 3 centimetres long and several millimetres broad, with well-defined terminations. It was also melted with 30 per cent. of dry chloride of sodium, in the hope that the compound would crystallize regularly in a fused matrix of chloride. On treating the product broken into small pieces with water, much chloride of calcium was dissolved, and the residue, which became porous, presented a

multitude of well-defined but always extremely small crystals. When augite is melted in an air-furnace, and when, consequently, cooling takes place rapidly, the mass is sometimes saccharoidal; but it never presents crystals, and most frequently it is compact and vitreous. B. This idea of obtaining crystals in a matrix fusible at a strong heat is similar in principle to that which Ebelmen long afterwards adopted with so much success in the formation of various crystals, Ebelmen replacing chloride of sodium by boracic acid or borax.

Product a well-melted glassy mass, translucent like opal; in some places crystalline. Sefström.

48. (S.) Melted into a compact mass, free from bubbles, stony, not at all glassy, translucent; fracture crystalline, but not nearly so much so as that of ordinary augite. B.

Product a well-melted partially crystallized enamel. Sefström.

49. (S.) Compact, free from bubbles, milk-white, opaque or slightly translucent, presenting almost throughout prisms grouped in different directions, but not so prominently as No. 47. B.

Product a well-melted opalescent glass having a granular fracture. Sefström.

50. (S.) Melted with 30 per cent. of chloride of calcium, it gave a compact mass, white, crystalline, resembling Carrara marble. After having been broken up and digested with water, it presented a very lamellar structure, and here and there little pearl-white prisms, sometimes fasciculated and sometimes grouped in different ways, but of which none had a termination. (S.) When the same mixture was melted with 3.3 per cent. of fluor-spar, a very beautiful white button was obtained, compact, very hard; fracture crystalline in some parts, and presenting in others radiated bundles, composed of acicular prisms, which could not be measured. B.

51. (S.) Button scoriform on the surface, but compact in the centre; fracture uneven, granular, opaque; it could not have been very liquid. B.

Product a pearl-coloured enamel, which appeared to be easily fusible.² Sefström.

52. (S.) Melted into a compact mass, free from bubbles, hard, tenacious, opaque, stony; fracture uneven, presenting scarcely any indication of crystalline structure. B.

53. (S.) Melted into a button slightly bubbly, translucent; fracture granular, presenting some crystalline points. B.

54. (S.) Button contained cavities, in which were small grains, a sign that the matter was not homogeneous, and, consequently, that it had not been fully melted. B.

55. (S.) Perfectly melted, porcelain-white, very hard, opaque; fracture uneven, dull, in which here and there very small crystalline grains could be distinguished. The composition of this mixture is the

² In Erdmann's Journal the formula $SC^2 + MS^2$ is given, and the same appears in the Jern-Kontoret's Annaler (1828, p. 187). It appears to be a mis-

print for the one which I have introduced, as in every other case the silica (S) is placed after, and not before, the base.

same as that indicated by the formula of *garnet*, $3\text{RO}, \text{SiO}_3 + \text{R}^2\text{O}^3, \text{SiO}_3$ [$3\text{RO}, 2\text{SiO}^2 + \text{R}^2\text{O}^3, \text{SiO}^2$], but the form of *garnet* in the product could not be recognised. (S.) The same compound melted with 7.5 per cent. of fluor-spar gave a compact button, free from bubbles—in part glassy and quite transparent, and in part translucent and waxy, but without the least appearance of crystallization: it resembled *hydrophane*. Treated with chloride of calcium, it gave a compact button without any appearance of crystallization; but which, after having been washed, presented in the centre of the mass a multitude of very brilliant small crystals. With its own weight of chloride of barium, it gave a compact, slightly crystalline button, resembling white marble, and which, after having been washed, presented a very decided crystalline structure, but there were no regular crystals. B.

56. (S.) Button compact, free from bubbles, white, slightly translucent, fine-grained, and lamellar. It is very fusible, and vitreous when rapidly cooled. B.

Product a blue-green well-melted glass, of which the specific gravity was 2.55. In another experiment, in which the blast was scarcely continued half an hour, the product was also melted, but it was porous. Sefström.

57. (S.) Button filled with cavities, stony; fracture uneven, granular, opaque, and of a beautiful white. B.

58. (S.) Button compact, free from bubbles; fracture uneven, granular, opaque, presenting no sign of crystallization. B.

Product a well-melted green glass. Its specific gravity in one experiment was 2.67, and in another 2.77. Sefström.

58a. Not given by Berthier. This mixture melted readily into a sooty glass, which was dichroic. Before the blowpipe it swelled up into white froth. Two experiments were made: in one the specific gravity of the product was 2.65, and in the other 2.79. Sefström.

58b. Not given by Berthier. Product similar to the last, but somewhat difficult to melt before the blowpipe. Its specific gravity was 2.56. Sefström.

59. (S.) Button filled with large cavities, opaque; fracture uneven, granular, dull, without sign of crystallization. B.

60. (S.) Melted into a compact button, stony, opaque; fracture saccharoidal; the grains were very distinctly crystallized and transparent. B.

61. (S.) Button compact, free from bubbles, very tenacious; fracture uneven, thin fragments translucent, resembling compact *quartz*, without sign of crystallization. B. This is identical in composition with a crystallized slag which frequently occurs in South Staffordshire, and of which an analysis has been given (see p. 49).

62. (G. f.) Remained quite pulverulent. B.

63. (G. f.) Button stony and tenacious to the depth of 1 or 2 millimetres, but pulverulent in the centre. B.

64. (G. f.) Melted into a compact mass, free from bubbles, very tenacious; fracture waxy, a little shining. B.

65. (G. f.) About the same as No. 64. B.

66. (S.) Completely melted. Button compact, stony, opaque; fracture even or uneven, slightly shining. B.

Product well-melted after an hour's blast. In fracture it resembled compact *dichroite*. Sefström.

67. (S.) Completely melted. Like No. 66; fracture uneven, dull. B.

68. Bubbly; finely granular in one part, and confusedly crystalline in another; cavities lined with microscopic crystals. B.

69. Very easily melted; mass lamellar, with large intersecting cleavage-planes, very brilliant, deep olive-grey; on the surface was seen an indication of crystallization in rectangular prisms. B. This compound perforates a clay crucible with great rapidity. It not unfrequently occurs beautifully crystallized in refinery and puddling-furnace slags. It is *olivine* in which the magnesia is wholly replaced by protoxide of iron.

70. Melted into a compact mass; fracture uneven, presenting only in some places indications of crystallization; colour pale-olive and greyish. B.

71. Melted into a compact homogeneous mass; fracture uneven or conchoidal, shining, opaque, olive-grey; without action on the magnet. This silicate was melted in a clay crucible without permeating it. B. These silicates were prepared in wrought-iron crucibles enclosed in clay crucibles. It is doubtful whether any other silicate than that, in which the oxygen of the silica is equal to that of the protoxide of iron, can be formed. The results of various experiments on this subject will be found recorded in the volume on Iron and Steel by the Author. When a mixture of silica with oxide of iron, in larger proportion than that indicated in No. 69 of the table, is strongly heated, an *apparently* homogeneous liquid product is obtained; but when the attempt is made to pour it out of the crucible, what runs out has the formula of No. 69, while there remains in the crucible a pasty mass containing magnetic oxide of iron.

72, 73. The mixtures did not decrease in volume: there was no combination. The buttons were tenacious, of a deep-grey colour, and magnetic; their powder was red, and grains of oxide of iron might be distinguished in it, of which the surface was metalloid in appearance. Berthier supposed that they had been reduced to magnetic oxide by the gases of the furnace. B. It is now known that when sesquioxide of iron is exposed to a high temperature, it is reduced to magnetic oxide without the intervention of any reducing agent; and that when a mixture of sesquioxide of iron and silica is strongly heated, even in the presence of atmospheric air, silicate of protoxide of iron is formed, with the evolution of oxygen.

74. Compact; presenting brilliant cleavage-planes in some parts, and on the surface radiated crystallization like sulphide of antimony. B.

75. Compact, free from bubbles, strongly magnetic; fracture uneven, vitreous, or confusedly crystallized in radiated bundles. B.

76. Similar to No. 75. B.

77. Perfectly melted, porous, opaque, presenting no sign of crystallization. B.

78. Melted in a clay crucible into a compact mass, free from bubbles, extremely tenacious; fracture slightly conchoidal or waxy, shining, only translucent on the edges; by reflection it appeared green, almost black; but when seen by transmitted light in thin laminae, it had the colour of resin; it scarcely affected the magnet; although it had been very liquid, it had not attacked the crucible. B.

79. Melted in a clay crucible into a compact black glass; fracture largely conchoidal, very brilliant; scarcely translucent on the edges; yellowish-brown in thin slices, without action on the magnet; half the matter had passed through the crucible. B.

80. Appeared to have only been in the pasty state; contained a large central cavity; blackish-grey in the interior of the mass; fracture uneven, opaque; in contact with the crucible vitreous, brilliant but opaque, very strongly magnetic; it had not attacked the crucible. B.

81. Completely melted into a brilliant black glass, very hard and tenacious, slightly bubbly, fracture conchoidal, shining, opaque even in the thinnest slices; powder black without any red tinge, strongly magnetic; it had not attacked the crucible. B. Berthier concluded that some protoxide was formed by the reducing action of the gases of the furnaces; but the same result might occur without, as previously stated under Nos. 72, 73.

82. (S.) Melted into a compact mass, dull-green, fracture somewhat lamellar, very fragile, appeared to be here and there mixed with brown oxide of manganese; when broken in small pieces and breathed upon, the fetid odour of impure hydrogen was perceived, yet no metallic grains could be observed. B.

83. (S.) Melted into a compact button, free from bubbles and without the least vitreous appearance, greyish-green, lustre fatty, strongly translucent, cleavage in various directions in large brilliant plates having the form of *olivine*. (G. f.) Melted it gave an olive-green button, opaque or scarcely translucent on the edges, having in the centre a great cavity filled with the rudiments of large crystals; there was a little grain of metallic manganese weighing $\frac{1}{300}$ of the weight of the mass. B.

84. (S.) Button pale flesh-red, opaque or scarcely translucent, free from bubbles, lamellar throughout, with large very brilliant intersecting plates; this structure rendered it very fragile; it must have been very liquid. B.

85. (S.) Button scoriform, filled with cavities, easily crushed between the fingers owing to its structure, but very hard, scratched glass strongly; fracture granular and dull, through the greater part of the mass, lamellar in some points, opaque, aspect earthy, green externally, and clear pale-brown (*blond*) in the interior; the matter must have been softened, but not completely melted. B.

86. (S.) Button perfectly melted, very clear grey, slightly translucent, fracture uneven and a little waxy, presenting here and there

signs of crystallization in prisms. (G. f.) It gave a compact button, free from bubbles, fracture largely conchoidal and shining, transparent and smoky (*couleur enfumée*). B.

87. (S.) Button compact, free from bubbles, colourless or slightly olive-grey, strongly translucent, lustre pearly, fracture curved-lamellar, entirely composed of fasciculated not very distinct prisms; but the crystallization was very apparent on the surface from the terminations of the prisms. B.

88. (S.) Button compact, slightly translucent, colour varying from asparagus-green to yellow-brown (*jaune-blond*), very lamellar, plates fibrous twisted (*contournées*). B.

89. (S.) Button very well melted, fragile, largely lamellar, strongly translucent, slightly greenish. B.

90. (S.) Button scoriform, and grey externally, compact with a few bubbles in the interior, fracture lamellar or scaly, white brilliant and translucent; there must have been complete fusion, without great liquidity. B.

91. (S.) Button well-rounded, compact, without the slightest bubble, clear-grey, fracture stony, dull. B.

92. (S.) Button like No. 91; fracture lamellar: the plates were lustrous and translucent. In another experiment the button was scoriform and bubbly, scarcely translucent on the edges. B.

93. (S.) Button compact, free from bubbles, grey or a little greenish, slightly translucent, fracture uneven, waxy, feebly shining, presenting here and there microscopic crystalline particles. B.

94. (S.) Button compact, free from bubbles, fracture rough (*raboteuse*), glassy, shining, clear olive-green in the greater part; granular, greyish, and opaque in other parts, very tenacious, without any sign of crystallization. B.

95. (G. f.) Button rounded, compact, almost free from bubbles, fracture vitreous, brilliant, olive-green, scarcely translucent at the edges; the fusion must have been a little pasty. B.

96. Heated in an iron crucible. Product well-melted, homogeneous, very bubbly, fracture uneven and dull, aspect stony, very clear grey, without any sign of crystallization. B.

The green and blue colours of some of the foregoing compounds were probably due to the presence of oxide of iron.

DEDUCTIONS FROM THE FOREGOING EXPERIMENTS.

Berthier has interspersed through the descriptions of his experiments a series of deductions, amongst which are the following:—

1. Weight for weight, soda fluxes^s more than potash.
2. A mixture of potash and soda is more fluxing than either alkali separately.
3. The alkaline silicates never acquire a stony aspect, and always produce glasses without any indication either of crystallization or of lamellar structure, whether rapidly cooled or left to cool slowly as in a porcelain-furnace.

^s The verb to flux is in common use amongst metallurgists and workers in metals.

4. The alkaline silicates always give great fusibility to the compounds which they form with other silicates. It is remarkable that compounds containing a somewhat considerable proportion of alkali preserve, like the alkaline silicates, their vitreous state when cooled very slowly, and do not acquire the stony aspect and crystalline structure which are thereby induced in most of the other silicates.

5. Only those silicates of baryta fuse well which contain less baryta than $3\text{BaO}, 2\text{SiO}_3$ [BaO, SiO_2], and less silica than $\text{BaO}, 4\text{SiO}_3$ [$\text{BaO}, 6\text{SiO}_2$].

6. Strontia is less fluxing than baryta.

7. No silicate of alumina is completely fusible at the highest temperatures attainable in furnaces (that is, such as were in use when Berthier wrote), but some of them soften, and all become more or less strongly agglomerated. The silicates of alumina, $\text{Al}_2\text{O}_3, 2\text{SiO}_3$ [$\text{Al}_2\text{O}_3, 3\text{SiO}_2$], and $\text{Al}_2\text{O}_3, 3\text{SiO}_3$ [$2\text{Al}_2\text{O}_3, 9\text{SiO}_2$], appear to soften most of all. Their tendency to fuse may be diminished by the addition either of silica or alumina.

8. Amongst the alkalies, alkaline earths, and earths, the fluxing property with respect to silica increases or decreases with the chemical energy of the base. It is to be observed that the solubility in water follows the same order, and probably the same is true of the fusibility proper to each base.

9. Amongst the simple metallic silicates the fusibility is proportionate to the chemical energy of the oxide. But this relation ceases when we compare bases of different classes: for example, the alkalies, alkaline earths, and earths with metallic oxides. Thus oxide of lead is infinitely more fluxing than baryta, although it is separated from all its combinations by baryta. The relation, furthermore, does not always hold good with metallic oxides, which, in a chemical sense, are not very remote from each other. Thus oxide of zinc is a powerful base, and yet produces a comparatively infusible silicate, whereas protoxide of iron produces a remarkably fusible silicate.

10. The fusibility of simple silicates appears to depend on three causes—the fusibility, proper to each base; its chemical energy; and the proportion in which it enters into the compound.

11. With respect to double and multiple silicates, their fusibility depends upon that of the component silicates. A silicate which is infusible *per se* may always be melted by combining it with a proper quantity of a fusible silicate. It appears, even, that the fusibility of multiple silicates is greater than that of the mean⁴ of the component silicates; for many infusible, or difficultly fusible, silicates may, in combining with each other, form very fusible double silicates, for example, silicate of lime and magnesia, of lime and alumina, &c.

⁴ Berthier's words are: "Il paraît même que la fusibilité des silicates multiples est plus grande que la fusibilité moyenne des silicates composants" (i. 430). Here Berthier, I presume, means, that if we take a mixture of equal weights, say, of three silicates, of which the respective fusibilities may be represented by the numbers 1, 2, 3, the fusibility of the triple silicate would be greater than 2, which is the calculated mean fusibility. But if this be so, the reason assigned in the second clause of the sentence does not apply.

12. When a simple or multiple silicate, containing a somewhat large proportion of alkali, is heated with a fixed and irreducible base, this base sets free part of the alkali, which volatilizes. Thus 15 grms. of silicate of soda, containing 10·35 of silica, and 4·65 of soda, were heated to 150° p. with 5·6 grms. of lime, when a button was obtained which weighed only 19·2 grms.; so that 1·4 grm. of soda had been volatilized. The button was compact, free from bubbles, opaque, with a stony fracture, somewhat shining. There is reason to believe that volatilization of alkali is effected by such a reaction in blast-furnaces.

13. A clay, of whatsoever kind, always melts into glass when heated to 150° p. with half its weight of carbonate of potash or soda; part of the carbonate infiltrates into the carbonaceous lining of the crucible before combination occurs, and there remains in the melted product only about 12 to 15 per cent. of its weight of carbonate.

14. Lime, which forms infusible or very difficultly fusible compounds with silica alone, may produce, with a great number of infusible or slightly fusible silicates, compounds which melt easily.

15. Amongst the compounds, which silica may form with lime and alumina, the most fusible are comprised between those in which the oxygen of the silica is double the sum of that of the lime and alumina, and those in which the oxygen of the silica is half the sum of that of the lime and alumina; and these compounds are fusible in proportion as the relation between the bases approaches that of $6\text{CaO} : \text{Al}_2\text{O}_3$ [idem]. They still melt well when the relation is $3\text{CaO} : \text{Al}_2\text{O}_3$ [idem], but they become much less fusible when the relation is $3\text{CaO} : 2\text{Al}_2\text{O}_3$ [idem]. The ultimate composition of clays which are richest in alumina may, with some exceptions, be expressed by the formula $\text{Al}_2\text{O}_3, 2\text{SiO}_2$ [$\text{Al}_2\text{O}_3, 3\text{SiO}_2$]. Hence it follows that, by the addition of a proportion of lime intermediate between 3CaO and 6CaO [idem], or the equivalent in carbonate of lime, they ought always to melt well; and that the fusion ought to be still more easy, when, in addition to lime, silica is also added in a proportion ranging from SiO_2 to 4SiO_2 [$1\frac{1}{2}\text{SiO}_2$ to 6SiO_2]. But the addition of silica is nearly always superfluous, because clays are rarely free from admixture with siliceous sand. Any clay whatsoever may by the addition of from half to three-quarters of its own weight of carbonate of lime be rendered sufficiently fusible to allow shots of metal to sink through the mass and collect into a button at the bottom. When, as sometimes happens, clays are mixed with hydrate of alumina, it becomes necessary to add at the same time silica and lime. The addition of a small proportion of different bases greatly increases the fusibility. Thus the silicate composed per cent. of—

| | |
|------------------------------|-------|
| Silica | 38·0 |
| Lime | 50·0 |
| Alumina | 6·5 |
| Magnesia | 2·0 |
| Protoxide of manganese | 3·5 |
| | <hr/> |
| | 100·0 |
| | <hr/> |

melts into a compact enamel-like mass, of a greenish colour, here and there lamellar, but which is sufficiently liquid to allow shots of metal to pass through it.

16. Magnesia may, like lime, cause the fusion of the silicates of alumina, but it is much less fluxing.

SUPPOSED SULPHO-SILICATES.

Plattner heated a mixture of 29.1 parts of silica and 108.0 of sulphate of baryta (*heavy spar*) in a carbon crucible. In this mixture the ratio between the silica and baryta is the same as in the silicate of the formula $3\text{BaO}, 2\text{SiO}_3$ [BaO, SiO_2]. The product was a greyish-yellow, compact, melted mass, of which the fracture was uneven, apparently crystalline, but without lustre. Its surface was polyhedral, iron-black (probably due to carbon), and of a semi-metallic lustre. It evolved a strong hepatic odour. When the powdered mass was treated with water, sulphuretted hydrogen was liberated, and a small quantity of sulphide of barium was dissolved; and when acted upon by hydrochloric acid, it was only very imperfectly decomposed with the evolution of the same gas. This melted product was produced at a far lower temperature than that required for the formation of the corresponding silicate of baryta, and Plattner inferred that it consisted of a combination of silica with oxysulphide of barium. A similar experiment was made with sulphate of lime (calcined *gypsum*). The silica and lime were in the proportion necessary to form the silicate of the formula CaO, SiO_3 [$2\text{CaO}, 3\text{SiO}_2$]; the mixture was exposed in a carbon crucible to a temperature corresponding to the melting-point of an alloy of 42 per cent. of gold and 58 per cent. of platinum. The product was not melted, but consisted of a greyish-white, easily pulverizable, sintered mass, which evolved a tolerably strong hepatic smell. In neither of these experiments was the product analysed, and, consequently, there is no certain evidence to prove the precise nature of the reactions and to justify a belief in the existence of sulpho-silicates. Sulphate of baryta is so easily reduced at a low temperature that Mr. Sewell, of Nottingham, many years ago, obtained a patent for the production of carbonic acid by heating a mixture of sulphate of baryta and carbon in a common gas-retort. I visited Mr. Sewell's works and saw the process in operation. As in Plattner's experiments carbon crucibles were employed, the formation of sulphides is readily explained, and the temperature at which their formation would occur is probably much below that which would be necessary to effect the combination of silica with either lime or baryta. Le Play⁵ admits the existence of a sulpho-silicate of iron, but, as it appears to me, on insufficient chemical evidence.

⁵ Description des Procédés métallurgiques, etc. p. 212.

ACTION OF HEAT ON CERTAIN COMPOUNDS NOT
CONTAINING SILICA.

ALUMINATES.

That alumina may act the part of an acid as well as that of a base is proved by the composition of the minerals termed *spinels*, which occur well crystallized, and consist exclusively of alumina and a base of the RO type, combined in atomic proportions. Beautifully crystallized compounds of this kind have been artificially prepared by Ebelmen. On the other hand, in various minerals, such as *staurolite*, *cyanite*, and *kaolinite*, alumina must be regarded as acting the part of a base, silica being the acid. But in many silicates containing both alumina and bases of the RO type, the function of alumina cannot, in the present state of our knowledge, be determined with certainty. From the foregoing experiments it appears that when a mixture consisting of silicate of lime of the formula $3\text{CaO}, 2\text{SiO}_3$ [CaO, SiO_2], with sufficient lime to form the silicate of the formula $3\text{CaO}, \text{SiO}_3$ [$2\text{CaO}, \text{SiO}_2$], is exposed to a very high temperature, a fritted mass may be produced; but this mass becomes speedily disintegrated, and much of the lime remains in a caustic state, as though it had only been mechanically diffused through the silicate. Now Sefström found that when alumina was added to this mixture of silicate of lime and lime, in the proportion requisite to form an aluminate of the formula $3\text{CaO}, 2\text{Al}_2\text{O}_3$ [*idem*]⁵—that is, a mixture represented by the formula $3\text{CaO}, 2\text{SiO}_3 + 3\text{CaO}, 2\text{Al}_2\text{O}_3$ [$3(\text{CaO}, \text{SiO}_2) + 3\text{CaO}, 2\text{Al}_2\text{O}_3$]⁶—the effect of heat was quite different. A well-melted mass was then obtained, of which the surface was rendered uneven by fine acicular crystals. At the upper part it was blue-grey, but underneath, where it was in contact with the charcoal lining, it had the lustre of iron, which is often produced in slags by the presence of the smallest amount of iron in the reagents employed. In the colour and appearance of the fracture it resembled phosphate of lime; its specific gravity was 2.888.

ALUMINA AND LIME.—The following experiments were made by Sefström on the formation of aluminates of lime in the furnace.

$3\text{CaO}, 2\text{Al}_2\text{O}_3$ [*idem*].—From a mixture composed according to this formula a porous dirty-yellow coloured mass was obtained. In another trial the product was compact, black, and of the specific gravity 2.76. When heated before the blowpipe, it became yellow, and then exactly resembled yellow wax. In a third experiment, after an hour's blast, a product similar to the last was obtained. Of all the aluminates which Sefström prepared this was the most fusible.

$\text{CaO}, \text{Al}_2\text{O}_3$ [*idem*].—Two experiments gave the same results. The product was a melted compact mass, of which, internally, the colour was between grey, yellow, and brown; in fracture it had a waxy lustre; it contained small white particles of unfused matter.

$3\text{CaO}, \text{Al}_2\text{O}_3$ [*idem*].—The product was a melted, glassy, yellowish-green slag.⁶ Before the blowpipe it was light-grey, and infusible.

* "Von einer Mittelfarbe zwischen Isabellgelb und Grasgrün."

This aluminate had the same remarkable property as the corresponding silicate, namely, that of falling to fine powder after a time. However, in the case of the aluminate this did not occur until after some months.

ALUMINA, LIME, AND MAGNESIA.—Berthier experimented upon the following mixtures:—

| | Alumina. | Lime. | Magnesia. |
|---|----------|----------|-----------|
| 1. $6\text{CaO}, 3\text{MgO}, \text{Al}_2\text{O}_3$ [idem] | 19.9 ... | 56.5 ... | 23.6 |
| 2. $3\text{CaO}, 3\text{MgO}, \text{Al}_2\text{O}_3$ „ | 27.5 ... | 39.3 ... | 33.2 |
| 3. $6\text{CaO}, 3\text{MgO}, 4\text{Al}_2\text{O}_3$ „ | 49.9 ... | 35.3 ... | 14.8 |
| 4. $4\text{CaO}, 3\text{MgO}, 3\text{Al}_2\text{O}_3$ „ | 47.0 ... | 33.8 ... | 19.2 |
| 5. $\text{CaO}, \text{MgO}, \text{Al}_2\text{O}_3$ „ | 53.5 ... | 25.5 ... | 21.0 |

1. (S.)⁷ Product granular, dull, fissured, very light, gritty between the fingers. It had a little diminished in volume.

2. (S.) Product granular, dull, sufficiently coherent, but gritty under the finger-nail. Considerably contracted.

3. (G. f.) Button well-melted, bubbly, pale olive-green, strongly translucent, fracture even, shining, and waxy, presenting no sign of crystallization.

4. (G. f.) Button well-rounded, compact, stony; fracture uneven, slightly shining, transparent in some parts.

5. (S.) Product granular and porous; the interior of the pores rounded, which proves that softening had occurred.

SESQUIOXIDE OF IRON AND LIME.

I found that a mixture of these substances in certain proportions yields a well-melted product. A mixture consisting of 160 grains of pure sesquioxide of iron and 100 of white marble (= 56 grains of lime)—that is, in the ratio of $\text{Fe}_2\text{O}_3 : \text{CaO}$ [idem]—was exposed in a covered clay crucible to a high temperature. It was perfectly melted, and when broken across resembled a black, opaque, vitreous slag: the crucible had one large perforation. In a second experiment a mixture, according to the same formula, of 40 grains of sesquioxide of iron and 25 of carbonate of lime was heated in a clay crucible lined with platinum foil. It was perfectly melted and escaped through the crucible.

Recently this reaction has again been investigated with the following results. An intimate mixture of 190 grains of sesquioxide of iron and 66.5 grains of lime was kept heated to whiteness in a platinum vessel during several hours in a muffle, the atmosphere of which is oxidizing, and left to cool in the furnace. The product appeared to have been perfectly melted, and consisted of a mass of interlacing acicular crystals, exceeding an inch in length: lustre, dark bright metallic; fracture, uneven and lustrous; very brittle; when in powder resembled brown-iron-ore in colour; sp. gr. 4.693; it was magnetic.

⁷ The letters (S.) and (G. f.) are Berthier's abbreviations previously explained at p. 62.

Its percentage composition was found by analysis to be as follows:—

| | |
|---------------------------|--------|
| Sesquioxide of iron | 73·39 |
| Protoxide of iron | 0·72 |
| Lime..... | 24·50 |
| Silica | 1·35 |
| Alumina | 0·10 |
| | <hr/> |
| | 100·06 |

This experiment, as also another in which much larger quantities of the same materials and in the same proportions were used, and similar results obtained, was conducted by R. Smith, in the laboratory of the Royal School of Mines.⁸

This compound may, in respect of composition, be regarded as *magnetite*, in which the protoxide of iron has been replaced by lime; or as a *spinel*, in which alumina has been replaced by sesquioxide of iron. It is analogous to the mineral termed *magnoferrite*, of which the formula is MgO, Fe^2O^3 [*idem*].⁹

It should be stated that Lampadius long ago experimented upon the action of heat on mixtures of lime and sesquioxide of iron; but owing to the conditions under which the experiments were made, the results are unsatisfactory.¹

ON FLUOR-SPAR AS A FLUX.

Fluor-spar occurs not unfrequently in ores. Its formula is CaF [CaF^2]; its composition² is—

| | |
|----------------|-----------|
| | Per cent. |
| Calcium | 51·28 |
| Fluorine | 48·72 |

At 60° p., according to Berthier, it neither melts nor softens, but contracts much. At a higher temperature it melts sufficiently easily into a transparent liquid, which crystallizes on cooling. Heated in the porcelain-furnace at Sèvres in a crucible lined with charcoal, it produced a compact mass, free from bubbles, and of a crystalline structure. The grains were very small, but transparent and well-defined, and under the microscope their form could be recognised.³

We have found it to melt at a high temperature, such as is attainable in an ordinary assay-furnace; and a lump, resulting from the fusion of 835 grains of purple fluor-spar in a platinum crucible, was largely crystalline throughout, and contained a central cavity, into which protruded octahedral crystals; it was slightly opalescent, glassy in lustre, and, when seen in mass, had a faint flesh tint.

The following experiments have been made on the fusibility of mixtures of fluor-spar and certain other substances.⁴

⁸ A record of these experiments will be found in the *Phil. Mag.* s. 4, 1873, xlv. 455.

⁹ Rammelsberg, *Handbuch der Mineralchemie*, 1860, p. 160.

¹ *Journ. des Mines*, xviii. 178.

² M. S. de Luca, *Comptes rendus*, 1860, li. 301.

³ Berthier, *Traité des Essais*, i. 480.

⁴ The letter B. is prefixed to those

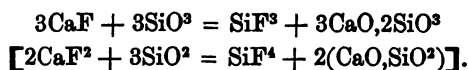
FLUOR-SPAR AND SILICA.—Mixtures of these substances, in the following proportions, were operated upon:—

| | 1. | 2. | 2a. |
|-----------------------|----------|----------|---------|
| | Grammes. | Grammes. | Grains. |
| Fluor-spar..... | 100 | 100 | 351 |
| Quartz in powder..... | 30 | 47 | 408 |

1. B. (S.) This and the following experiment by Berthier were made in clay crucibles, brasqued, i.e. lined with charcoal. Button perfectly rounded, compact, without the slightest bubble; fracture even, finely granular, and crystalline, resembling white statuary marble. It weighed 114 grms., so that there was a loss of 16 grms. The edges of the crucible were lined—especially towards the angles—with bubbly, colourless, and transparent glass, arising, according to Berthier, from the action of what he terms “fluo-silicic” gas (by which must be meant either hydro-fluo-silicic acid or, what is more probable, a mixture of fluoride of silicon and hydro-fluoric acid) upon the substance of the crucible. Berthier supposes this gas to have been produced by the action of the gases containing hydrogen (*gaz hydro-génés*), which were present in the furnace.

2. B. (G. f.) Button compact, free from bubbles, white, opaque, very hard; fracture stony, uneven, resembling compact quartz. It weighed 126 grms., so that there had been a loss of 21 grms. The edges of the crucible were coated with glass.

2a. By R. Smith, in my laboratory. Both substances were finely powdered, and intimately mixed together. The mixture was put into a crucible of platinum, contained within one of clay, the space between the two crucibles being filled with burnt china-clay. Thus arranged, and closed with a fire-clay cover, it was heated to whiteness in an air-furnace, and kept at that temperature during about an hour and a half, by which treatment it lost 50 grains in weight. It was again heated, exactly in the same manner and for the same time as in the first instance, when it suffered a further loss of 25 grains. The product seemed to have been well melted at the lower, but less so at the upper, part, of which the surface at the top was a little uneven and porous. It was opaque, white, and in fracture fine-grained, but feebly lustrous. The proportions operated upon were such as, supposing all the fluorine to have escaped as fluoride of silicon, and all the calcium to have been converted into lime at the expense of the oxygen of part of the silica (namely, that yielding the silicon to the fluorine), there would have remained only silicate of lime, of the formula of *wollastonite*, $3\text{CaO}, 2\text{SiO}^3$ [CaO, SiO^2], according to the reaction expressed by the following equation:—



which were made by Berthier. The letters (S.) and (G. f.) refer to the furnaces used (see p. 62). The numeral placed over the quantities taken is the number of the experiment.

If such a reaction had occurred, the loss in weight would have been three times as much as the actual loss, namely, 235 grains. Hence, it is clear that this reaction did not take place; and without further experiments and a knowledge of the composition of the product, which has not yet been analysed, the actual reaction cannot certainly be known.

FLUOR-SPAR, QUARTZ, AND ALUMINA.—A mixture of these substances, in the following proportions, was operated upon :—

| | 3. Grammes. |
|------------------------|----------------|
| Fluor-spar | 100 |
| Quartz in powder | 190 |
| Alumina | 40 |

3. B. (S.) Heated in a brasqued crucible. Button well-rounded, compact, without the least bubble; fracture partly lamellar, partly conchoidal, translucent, clear grey. It weighed 270 grms., so that the loss amounted to 60 grms.

FLUOR-SPAR, QUARTZ, AND KAOLIN.—A mixture of these substances, in the following proportions, was operated upon :—

| | 4. Grammes. |
|----------------------------------|----------------|
| Fluor-spar | 100 |
| Quartz in powder | 130 |
| Kaolin washed and calcined | 100 |

4. B. (G. f.) Heated in a brasqued crucible. Button well-melted, compact, translucent, white; fracture uneven, very hard. It weighed 287·5 grms., so that the loss amounted to 42·5 grms.

Berthier makes the following remarks. Fluor-spar acts as a flux in two ways: by combining directly with silicates and forming fusible compounds; but chiefly by acting upon silicates and causing an evolution of fluoride of silicon. Fluorine and silicon are thus removed, and the lime is relatively increased. The agency of gases containing hydrogen does not seem to be necessary to determine the reaction, for the calcium may be oxidized at the expense of the oxygen of the silica, and the silicon, reduced, escape in combination with fluorine.

FLUOR-SPAR AND SULPHATE OF BARYTA.—Mixtures of these substances, in the following proportions, were operated upon :—

| | 5. | | 6. | 7. |
|-----------------------|------------------|----------------|-------------|-------------|
| | a. Grains. | b. Grammes. | Grammes. | Grains. |
| Fluor-spar | 1 equivalent 195 | 9·87 | 2 eq. 19·74 | 1 eq. 97·5 |
| Sulphate of baryta... | 1 equivalent 585 | 29·16 | 1 eq. 29·16 | 2 eq. 585·0 |

5a. By R. Smith in my laboratory. In this, and experiment No. 7, Cornish crucibles were used. Fused at a bright red-heat, but not very liquid. Product hard, brittle; fracture indistinctly crystalline. There was a cavity in the centre lined with indistinct

crystals; it had a pink greyish-white colour, due, probably, to the fluor-spar.

5b. B. Clay crucibles were used in this and the following experiment. Although heated very strongly, it did not become perfectly liquid. Product intumesced in some parts; fracture granular-crystalline. The sides of the cavities were polyhedral, and some small prismatic crystals were perceived here and there.

6. B. Strongly heated; completely melted. Product compact; fracture slightly crystalline, a little translucent, colourless, no distinctly formed crystals.

7. By R. Smith. Did not melt so easily as No. 5. Product hard, brittle; fracture compact, with traces of indistinct crystalline plates; colour pink greyish-white.

FLUOR-SPAR AND SULPHATE OF LIME.—Mixtures of these substances, in the following proportions, were operated upon :—

| 7a. | | 8. | |
|----------------------|----------------------|-----------------|----------------------|
| Grammes. | | a. Grains. | b. Grammes. |
| Fluor-spar..... | 2 eq. 19·74 | 1 eq. 390 | 1 eq. 9·87 |
| Sulphate of lime ... | 1 eq. 21·64 (cryst.) | 1 eq. 680 (dry) | 1 eq. 21·64 (cryst.) |

| 9. | | 10. | |
|----------------------|-----------------|----------------------|----------------------|
| a. Grains. | b. Grammes. | Grammes. | |
| Fluor-spar | 1 eq. 195 | 1 eq. 4·93 | 1 eq. 2·47 |
| Sulphate of lime ... | 2 eq. 680 (dry) | 2 eq. 21·64 (cryst.) | 4 eq. 21·64 (cryst.) |

7a. B. Clay crucibles were used in this and the following experiments by Berthier. Melted at a rather strong heat. Product compact; fracture uneven, with only faint traces of crystallization.

8a. By R. Smith. In this, and experiment No. 9a, Cornish crucibles were used. This mixture melted at a lower temperature than that with sulphate of baryta, and became very liquid. Product hard, fragile, opaque, pinkish-white; fracture fibrous in the outer portion, but the centre part consisted of shining indistinct crystalline plates.

8b. B. Very quickly and completely melted and became extremely liquid. Product crystalline, consisting of large plates crossing each other in different directions; translucent, white, slightly pearly; it contained cavities in which were determinable crystals. It is the most fusible mixture of fluor-spar and sulphate of lime.

9a. By R. Smith. Result similar to No. 8a, but the crystallization was more distinct.

9b. B. Became very liquid. Product compact, free from bubbles, white, slightly translucent; fracture granular, foliated, with very brilliant plates.

10. B. Although heated very strongly, it did not completely melt, but was only softened. Product very bubbly, opaque, white; fracture finely granular; the internal surfaces of the cavities polyhedral.

FLUOR-SPAR AND SULPHATE OF SODA.—Mixtures of these substances, in the following proportions, were operated upon :—

| | 11. Grammes. | 12. Grammes. |
|-----------------------------------|-------------------|-----------------|
| Fluor-spar | 1 eq. 19·74 | 2 eq. 19·74 |
| Anhydrous sulphate of soda, 1 eq. | 35·68 | 1 eq. 17·84 |

11. B. Clay crucibles were used in this and the following experiment. Melted and became as liquid as water. Product contracted very much on cooling; compact; fracture granular, crystalline, and strongly translucent, but there were no isolated crystals.

12. B. Melted with slight effervescence, and became extremely liquid. Product resembled No. 11, but was harder and more tenacious.

FLUOR-SPAR AND BONE-ASH.—Mixtures of these substances, in the following proportions, were operated upon :—

| | 13. | 14. Grammes. |
|------------------|-------------------|-------------------|
| Fluor-spar | } equal weights { | 4 eq. 19·74 |
| Bone-ash..... | | 1 eq. 27·67 |

13. By R. Smith. A Cornish crucible was used. Melted at a red-heat. Product compact, hard, brittle, opaque, white; fracture slightly conchoidal. The central part consisted of small, interlacing, acicular crystals.

14. B. A clay crucible was used. Contracted, so as no longer to touch the sides of the crucible; softened, but without melting. Product very coherent; bubbly, especially on the lower part; fracture dull and stony.

According to Berthier fluor-spar has no action on sulphides, and when melted with them there is usually simple mixture; but, when the sulphide is very fusible and heavy, it separates and subsides to the bottom of the crucible.

PLATTNER'S EXPERIMENTS ON THE MELTING-POINTS OF SILICATES.

METHOD OF DETERMINATION.

In these experiments Plattner endeavoured to determine the precise thermometric melting-points of various silicates occurring as slags, and to this end he availed himself of the method proposed and employed by Prinsep for the measurement of high temperatures.⁵ This method consists in the application of what Prinsep terms *pyrometric alloys* of gold and platinum. From the fusion of pure gold to that of pure platinum he assumed 100 degrees, increasing the percentage of the latter metal in the alloy 1 per cent. for each successive

⁵ Phil. Trans. 1828, i. 79.

degree. The melting-point of gold is the zero of this scale. Prinsep did not suppose that these hypothetical degrees represented equal increments of heat throughout the scale, but, as he observes, they always indicate the same intensity. The alloys are rolled out and cut into pieces of the size of a pin's head; eight or ten of these alloys are placed at a time in a small *pyrometer cupel*, *a*, each in a separate cavity, as shown in the annexed woodcut, fig. 3. In three of these

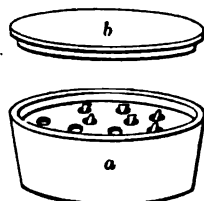


Fig. 3. Pyrometer cupel.

cavities the metal is supposed to be melted. The cupel is provided with a nicely fitting lid, *b*. Now, as Prinsep observes, when a series of such alloys has once been prepared, the heat of any furnace may be expressed by the alloy of least fusibility which it is capable of melting; but Plattner has attempted to assign precise temperatures in Centigrade degrees to the melting-points of these alloys. He adopted the principle of a process which had been previously employed by B. de Saussure in the estimation of high temperatures.* The process consists in ascertaining the greatest amount of any substance which can be melted before the blowpipe, and comparing the weight, computed from the diameter, of the bead with that of the greatest amount of silver which can be melted in the same manner. Daniell, by means of his platinum pyrometer, found the melting-points of silver and gold to be respectively 1023° C. and 1102° C.; and, accepting these as correct, Plattner proceeded to deduce the melting-point of platinum. He *assumed* that the melting-point of alloys of silver and platinum would be the mean of those of the two metals. He found by experiment that an alloy composed of 9.5 per cent. of platinum and 90.5 of silver had the same melting-point as gold, and hence he deduced the melting-point of platinum as follows:—

Let x be the melting-point of platinum.

$$\frac{9.5x + (90.5 \times 1023)}{100} = 1102, \text{ whence } x = 1854.5^\circ \text{ C.}$$

He next ascertained the maximum amount of gold which could be melted in a *given* time by a *given* blowpipe flame produced by a blast of constant but very slight pressure. The fusion was effected in small clay crucibles of the same shape and size ($\frac{1}{8}$ inch high and $\frac{3}{8}$ inch in diameter at the top, Prussian measure). In order that the heat might be uniformly applied, each crucible was placed in a cavity in the end of a piece of good soft charcoal about four inches long and one inch square. The maximum amount of gold thus melted was 2290 milligrammes, and 1990 milligrammes of an alloy composed of 1760 of gold and 230 of platinum were melted in the same time, under the same conditions. When more gold, or ever so small

* Die Anwendung der erwärmten Gebläseluft im Gebiete der Metallurgie, F. Th. Merbach, 1848, pp. 288 *et seq.* Platt

ner's experiments are recorded in extenso in this work, from which I have derived my knowledge of his results.

a quantity of platinum, was added, the fusion was rendered imperfect. Now in the case of the gold, the number of degrees of heat may be estimated as 2290×1102 (the melting-point of gold), but in the case of the alloy, the number of degrees represented by the fusion of the gold is 1760×1102 . It was inferred that the number of degrees required for the fusion of 230 of platinum was equal to that required for 530 of gold, that is, the difference of the weight of gold fused in the two cases. Hence the melting-point of platinum should be $\frac{530 \times 1102}{230} = 2539^\circ \text{C}$. In a similar manner

Plattner ascertained that 100 milligrammes of an alloy composed of 70 of gold and 30 of platinum could be melted under the same conditions and in the same time as 100 milligrammes of cast-iron, of which the melting-point, according to Daniell, is 1530°C . From these latter data the number 2534°C . was deduced as the melting-point of platinum.

OBJECTIONS TO THE METHOD.—This method of estimating high temperatures involves an assumption that the melting-point of alloys is the mean of the melting-points of their component metals, and this assumption is opposed to numerous well-ascertained facts. Besides, it is obvious that, notwithstanding all the precautions which appear to have been taken by Plattner in conducting his experiments, it must be extremely difficult, not to say impossible, to ensure the necessary identity of conditions in successive experiments, and to determine the exact moment at which perfect fusion is effected. The result of the experiment with cast-iron, irrespective of the objections just stated, must be regarded as worthless, because under the term cast-iron may be comprised varieties of metal which widely differ, both in chemical composition and physical characters. Although we may not admit the correctness of the principle of Plattner's measurement of high temperatures, yet we may accept his experimental results as affording practical information of value. The melting-points of metals and their alloys are fixed and unvarying, except under extraordinary conditions of great pressure; and, as they extend through a very wide range of temperature, they may be conveniently employed in the comparison of high temperatures.

RESULTS OF EXPERIMENTS.

It is stated that the fusion of a silicate may be effected at a *lower* temperature than that at which its components will originally fuse when they enter into combination; but I doubt whether this statement has been satisfactorily proved. That a longer time may be necessary to effect the fusion at a given temperature in the latter case than in the former must be admitted, but it is probable that fusion would be equally well effected in both cases at the same temperature, provided sufficient time be allowed. Plattner made numerous experiments to ascertain the melting-points of various silicates as indicated by the fusion of alloys of gold and platinum; and for

this purpose he employed a pyrometer cupel made of well-burnt fire-clay and an air-furnace. He also effected the fusion of these silicates before the oxyhydrogen blowpipe. Nos. 15, 16, 26, 27, 31, 32, 42, 44, in the table, pp. 60, 61, were melted at the same temperature as an alloy consisting of 42 per cent. of gold and 58 of platinum; Nos. 35, 36, at the same temperature as an alloy of 41 gold and 59 platinum; Nos. 47 and 56 at the same temperatures, respectively, as alloys of 45 gold and 55 platinum, and 43 gold and 57 platinum; and Nos. 69 and 70, at the same temperatures, respectively, as alloys of 52 gold and 48 platinum, and 49 gold and 51 platinum. Other results obtained by Plattner are recorded in the following table.

TABLE OF THE MELTING-POINTS OF SILICATES AS INDICATED BY THE FUSION OF ALLOYS OF GOLD AND PLATINUM.

COMPOSITION of the Silicates experimented on.

| | 1. | 2. | 3. | 4. | 5. | 6. |
|-----------------------------------|-------|-------|-------|-------|-------|-------|
| Silica | 50·0 | 56·0 | 48·0 | 50·0 | 36·5 | 32·7 |
| Alumina | 17·0 | 6·0 | 9·0 | 6·0 | 8·5 | 7·0 |
| Baryta | .. | .. | .. | 1·5 | .. | .. |
| Lime | 30·0 | 22·0 | 4·5 | 3·0 | 4·0 | .. |
| Magnesia | .. | 10·0 | 1·5 | 1·5 | 3·0 | .. |
| Protoxide of iron... | 3·0 | 2·0 | 37·0 | 38·0 | 40·5 | 60·3 |
| Protoxide of man- ganese | .. | 2·0 | .. | .. | .. | .. |
| Protoxide of lead... | .. | .. | .. | .. | 7·5 | .. |
| | 100·0 | 100·0 | 100·0 | 100·0 | 100·0 | 100·0 |

TEMPERATURE at which the Silicate melted when it was being formed, as indicated by the Melting-points of Alloys of Gold and Platinum.

| | Au. Pt. | Au. Pt. | Au. Pt. | Au. Pt. | Au. Pt. | Au. Pt. |
|-----------------------|---------|---------|---------|---------|---------|---------|
| In a carbon crucible | 46+54 | 46+54 | .. | .. | .. | .. |
| In an iron crucible | .. | .. | 59+41 | 56+44 | 75+25 | 67+23 |
| In a clay crucible... | .. | .. | 60+40 | 57+43 | 76+24 | 75+25 |

TEMPERATURE at which the Silicate melts after its Formation, as indicated by the Melting-points of Alloys of Gold and Platinum.

| | Au. Pt. | Au. Pt. | Au. Pt. | Au. Pt. | Au. Pt. | Au. Pt. |
|-----------------------|---------|---------|---------|---------|---------|---------|
| In a carbon crucible | 77+23 | 76+24 | .. | .. | .. | .. |
| In an iron crucible | .. | .. | 84+16 | 82+18 | 85+15 | 83+17 |
| In a clay crucible... | .. | .. | 84+16 | 82+18 | 85+15 | 84+16 |

REFRACTORY MATERIALS.

CRUCIBLES, FURNACES, FIRE-BRICKS, ETC.

FIRE-CLAYS.

CLAYS are termed *fire-clays*, or *refractory clays*, when they resist exposure to a high temperature without melting or becoming in a sensible degree soft and pasty. These clays differ much in degree of refractory quality. They occur in various geological formations, old as well as recent; but some of the best abound in the Coal-measures.

All clays as they occur in nature consist essentially of *hydrous silicate of alumina*; and upon the presence of the water of *combination* depends their *ficile* or plastic property, that is, their capability of being moulded into vessels or other objects when mixed with water and kneaded to a pasty consistency. All clays contain *hygroscopic water*, which may be expelled at 100° C. without lessening their plasticity. When, however, clay is heated to redness, it loses not only its hygroscopic water, but also its water of combination, and, as a consequence, it ceases to be plastic. In this dehydrated state it cannot directly *combine* with water and regain its plasticity, though it may *absorb* water with avidity. Pounded brick, for example, which is dehydrated clay, may absorb a considerable quantity of water, yet without regaining the slightest degree of plasticity.

It is important to note that there may be great variation in the composition and quality of clay from contiguous beds in the same pit, and even from the *same* continuous horizontal bed in the same locality.¹

In illustration of the first of these statements the following table is presented, showing the composition of fire-clay from seven different seams all lying in close proximity to each other in the Coal-measures and worked in the mines belonging to one fire-brick manufactory, situate a few miles west of Newcastle-on-Tyne. The thickness of these seams ranges from 1 to 5 feet. It is asserted that a supply of fire-clays, thus differing notably from each other, is advantageous to the manufacturer by enabling him to intermix them so as to produce material suitable for various purposes.²

¹ Brongniart, *Traité des Arts céramiques*, ii. 309. Erdmann's *Journal für praktische Chemie*, 1853, lviii. 67.

² Cowen on Fire-clay Goods, *Civil Engineer and Architect's Journal*, 1863, xxvi. 291.

COMPOSITION OF FIRE-CLAYS FROM NEIGHBOURING BEDS.

| | I. | II. | III. | IV. | V. | VI. | VII. |
|---|--------|--------|-------|--------|--------|-------|-------|
| Silica | 51.10 | 47.55 | 48.55 | 51.11 | 71.28 | 83.29 | 69.25 |
| Alumina | 31.85 | 29.50 | 30.25 | 30.40 | 17.75 | 8.10 | 17.90 |
| Oxide of iron (Fe_2O_3) ... | 4.63 | 9.13 | 4.06 | 4.91 | 2.43 | 1.88 | 2.97 |
| Lime | 1.46 | 1.34 | 1.66 | 1.76 | | | |
| Magnesia | 1.54 | 0.71 | 1.91 | trace | 2.30 | 2.99 | 1.30 |
| Water and organic matter | 10.47 | 12.01 | 10.67 | 12.29 | 6.94 | 3.64 | 7.58 |
| | 100.55 | 100.24 | 97.10 | 100.47 | 100.70 | 99.90 | 99.00 |

If we compare different clays together in respect to elementary composition, we find the relation between the silica and alumina to be extremely variable; and, accordingly, the formulæ which have been proposed to express their rational constitution are very discordant. This is in great measure to be explained by the fact that in many clays a large proportion of silica exists uncombined either in the form of sand, or in a much finer state of division. The grittiness of a clay is due to the presence of sand. Fresenius has investigated the clays of the Duchy of Nassau which are employed in the manufacture of pottery, and has attempted to determine the proportion of free silica which they contain.³ The sand and much of the finer silica may be separated by the following process of washing, which he adopted. He made use of the apparatus of Schulze for the *mechanical* analysis of soils which is represented in fig. 4. It consists of a glass vessel



Fig. 4. Schulze's apparatus, copied from his engraving of it.

10 inches high and $2\frac{1}{2}$ in diameter at the mouth, on which is fitted a brass ring, *a*, provided with an elbow-tube, for the outflow of water; and of a funnel-mouthed glass tube, *b*, 18 inches long, and about $\frac{1}{4}$ of an inch in diameter, but contracted at the lower end to about $\frac{1}{8}$ of an inch in diameter, which is placed in the glass vessel. In the instrument, as now constructed, there is fixed on the top of the ring, over the centre of the vessel, a flat strip of brass, in the middle of which is inserted vertically a short piece of brass pipe for receiving the funnel-mouthed glass tube, and keeping it upright. The upper part of the brass pipe is slit vertically through the axis, so that it may act like a spring and clip the glass tube firmly, thus enabling the operator to fix the lower end of the latter as far above the bottom of the glass vessel as may be desired. An ounce of air-dried clay may be operated on at a time. It is prepared by breaking it up and digesting it with a moderate quantity of water in a porcelain basin for half an hour, stirring gently with a pestle all the while, by which means it is thoroughly disintegrated. The mixture of clay and water is then poured into the glass, and water from a stop-cock attached to a reservoir is allowed to run into the funnel-

³ Erdmann's Journal für praktische Chemie, 1852, lvii. 65 *et seq.*

mouthed tube, the lower end of which should rest on the bottom of the glass; for if this precaution were not taken, the tube would become stopped up with clay. The clay is strongly agitated by this continuous stream of water, but only the finer particles are carried upwards and flow out through the side-tube. The water in the supply-tube should be kept at 8 inches above that in the glass. The sand is left at the bottom of the glass, and may be weighed after ignition. The matter removed by the current of water must be allowed to subside, and washed a second time, keeping the column of water in the supply-tube about $1\frac{1}{4}$ inch higher than that in the glass. The residue of very fine sand remaining in the glass is collected on a filter, ignited, and weighed. The second washing requires about 10 litres of water, and lasts from 3 to 4 hours. After the determination of the quantity of water in the raw clay, the proportion of clayey matter carried away in the process of washing may be found by deducting the sum of the weight of this water and that of the residual silica from the total weight of clay operated upon. Five kinds of air-dried clay yielded by this treatment the following results:—

| | 1. | 2. | 3. | 4. | 5. |
|-----------------------------------|--------|--------|--------|--------|--------|
| Sand | 24·68 | 11·30 | 8·91 | 7·74 | 6·66 |
| Very fine sand or sand-dust | 11·29 | 12·54 | 10·53* | 12·19 | 9·66 |
| Clay | 57·82 | 70·73 | 71·66 | 71·70 | 74·82 |
| Water | 6·21 | 5·43 | 8·90 | 8·37 | 8·86 |
| | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 |

1. From Hillaesheid. 2. From Bendorf. 3. From Baumbach. 4. From Grenzhausen. 5. From Ebernhausen.

* This is too high, owing to some clay having been carried over in the washing.

These clays were analysed, and the results are worthy of attention.

Boiling water extracted a small quantity of organic matter, chloride of sodium and sulphate of lime. The presence of these salts was to be expected, as they are always found in natural waters, and as clay has been deposited by the agency of water.

The solution obtained by digesting the clay at a gentle heat with dilute hydrochloric acid contained sesquioxide and protoxide of iron, traces of protoxide of manganese, lime, magnesia, alumina, soda, sulphuric acid, and phosphoric acid, which was detected by the molybdate of ammonia test. The *insoluble* residue contained silica, alumina, sesquioxide of iron, lime, magnesia, potash, and traces of soda.

A boiling solution of carbonate of soda extracted a small quantity of silica, which before being ignited in the usual way was yellowish-brown, from the presence of organic matter.

When the clay was heated for a considerable time with slightly diluted sulphuric acid, and the temperature towards the last increased so as to expel the excess of the acid, the clayey part was completely

decomposed with the separation of nearly the whole of the silica, which may then be separated from the intermixed sand by boiling with a solution of carbonate of soda.

The clay yielded decided evidence of the presence of ammonia, red litmus paper having become blue when suspended over the clay moistened with a solution of carbonate of soda and warmed.

The composition of the Nassau clays was found to be as follows, after drying at 100° C. :—

| | 1. | 2. | 3. | 4. | 5. |
|---------------------------|-------|-------|-------|-------|-------|
| Silica | 77·03 | 75·44 | 62·78 | 68·28 | 64·80 |
| Alumina | 14·06 | 17·09 | 25·48 | 20·00 | 24·47 |
| Sesquioxide of iron | 1·35 | 1·13 | 1·25 | 1·78 | 1·72 |
| Lime | 0·35 | 0·48 | 0·36 | 0·61 | 1·08 |
| Magnesia | 0·47 | 0·31 | 0·47 | 0·52 | 0·87 |
| Potash | 1·26 | 0·52 | 2·51 | 2·35 | 0·29 |
| Water | 5·17 | 4·71 | 6·65 | 6·39 | 6·72 |
| | 99·69 | 99·68 | 99·50 | 99·93 | 99·95 |

In No. 1 the proportion of soda was determined, and found to be 0·33 per cent.

By treatment with sulphuric acid the percentage of insoluble residue in the clays dried at 100° C. was found to be as follows :—

| | 1. | 2. | 3. | 4. | 5. |
|--------------------------------------|-------|-------|-------|-------|-------|
| Sand | 56·95 | 47·40 | 16·20 | 29·63 | 18·29 |
| Silica separated from combination... | 21·13 | 29·51 | 46·76 | 39·50 | 46·11 |
| | 78·08 | 76·91 | 62·96 | 69·13 | 64·40 |

On comparing the proportions of residue insoluble in sulphuric acid with those of the total silica stated in the foregoing tables of analyses respectively, it will appear that the sand must be nearly pure silica.

By boiling with a solution of carbonate of soda, the percentage of silica dissolved was as follows :—

| | 1. | 2. | 3. | 4. | 5. |
|--------------|------|------|------|------|------|
| Silica | 1·39 | 1·06 | 1·05 | 0·91 | 0·98 |

In the next table is presented the percentage of silica which existed in different states in the clays dried at 100° C.

| | 1. | 2. | 3. | 4. | 5. |
|---|-------|-------|-------|-------|-------|
| Silica in the form of sand ⁴ | 24·91 | 11·39 | 9·13 | 7·91 | 6·81 |
| do. do. fine sand ⁴ | 11·40 | 12·64 | 7·07 | 12·45 | 9·89 |
| do. in the finest state of division, carried over with the clay ⁵ } | 20·64 | 23·37 | 0·00 | 9·27 | 1·59 |
| Total silica existing as sand... | 56·95 | 47·40 | 16·20 | 29·63 | 18·29 |
| Silica in the state of hydrate..... | 1·39 | 1·06 | 1·05 | 0·91 | 0·98 |
| do. combined with bases ⁶ | 18·69 | 26·98 | 45·53 | 37·74 | 45·53 |
| Total silica | 77·03 | 75·44 | 62·78 | 68·28 | 64·80 |

In the next table is given the percentage composition of the clays after the deduction of the silica which existed as sand, and in the state in which it dissolves in a hot solution of carbonate of soda.

| | 1. | 2. | 3. | 4. | 5. |
|---|--------|--------|--------|--------|--------|
| Silica | 45·30 | 52·74 | 55·40 | 54·43 | 56·48 |
| Alumina | 34·08 | 33·41 | 31·04 | 28·85 | 30·36 |
| Sesquioxide of iron | 3·27 | 2·20 | 1·51 | 2·57 | 2·14 |
| Lime | 0·87 | 0·94 | 0·43 | 0·87 | 1·34 |
| Magnesia | 1·14 | 0·61 | 0·57 | 0·75 | 1·08 |
| Potash | 3·05 | 1·01 | 3·05 | 3·39 | 0·36 |
| Water | 12·29 | 9·08 | 8·00 | 9·13 | 8·24 |
| | 100·00 | 99·99 | 100·00 | 99·99 | 100·00 |
| With 100 parts of Sand | 137·03 | 92·09 | 19·60 | 42·70 | 22·68 |
| clay are associated (Silica as hydrate | 3·59 | 2·19 | 1·36 | 1·40 | 1·30 |
| The weight of original clay, con- taining 100 parts of clay freed from sand | 240·62 | 194·27 | 120·96 | 144·09 | 123·98 |

If we select the last three clays as containing the least sand, and calculate the ratios between the oxygen of the silica, alumina, and water, we obtain the following results (Fresenius):—

| | Silica. | Alumina. | Water. |
|-----------------|---------|----------|--------|
| 3. 6 | 3·02 | 1·48 | |
| 4. 6 | 2·86 | 1·72 | |
| 5. 6 | 2·90 | 1·49 | |

These numbers would lead to the formula $\text{Al}^2\text{O}^3, 2\text{SiO}^2 + 2\text{HO}$ [$\text{Al}^2\text{O}^3, 3\text{SiO}^2 + 2\text{H}^2\text{O}$] if the oxygen of the water be estimated at two-thirds of that of the alumina; or to the formula $2(\text{Al}^2\text{O}^3, 2\text{SiO}^2) + 3\text{HO}$

⁴ These numbers are somewhat higher than those previously given, because they are deduced from the clays dried at 100° C., whereas the latter were deduced from the air-dried clays.

⁵ These numbers are found by subtract-

ing the sum of the sand given under the other heads from the total quantity of sand stated in the table of analyses.

⁶ These numbers are found by subtracting the weight of sand and hydrated silica from the total weight of silica.

$[2(\text{Al}_2\text{O}_3, 3\text{SiO}_2) + 3\text{H}_2\text{O}]$ if it be estimated only at half that of the alumina. The percentage composition calculated from the first of these formulæ is—

| | |
|---------------|--------|
| Silica | 57·14 |
| Alumina | 31·72 |
| Water | 11·14 |
| | <hr/> |
| | 100·00 |

KAOLINITE.

Here the question naturally arises whether one definite hydrated silicate of alumina constitutes the essential basis of all the substances to which the name of clay is usually applied. On this subject the following evidence may be adduced:—

The existence of a definite crystallized natural hydrous silicate of alumina has been certainly established. It is the mineral designated kaolinite by the American mineralogists, Johnson and Blake.⁷ The same word was previously used as a synonyme for china-clay or kaolin, which is a corruption of the word Kaoling, the name of a mountain in China, where china-clay was obtained.⁸ It occurs in the state of scaly crystalline powder, which, under the microscope, is seen to consist of translucent or transparent, rhombic, rhomboidal, or hexagonal plates, flexible and inelastic, isolated or aggregated in bundles, either prismatic and usually curved, or fan-shaped; it is pearly in lustre, white, or coloured by the intermixture of oxide of iron or other matters; it crystallizes in the system called the orthorhombic by Dana and prismatic by Miller; the base of the crystals is marked with lines, arising from the edges of superimposed plates, and the cleavage is basal; in hardness it ranges from talc to midway between selenite and calcite; its specific gravity varies from 2·4 to 2·63; it usually constitutes a compact friable or mealy clay-like mass, greasy to the touch, and more or less plastic;⁹ it is decomposable by hot sulphuric acid, is insoluble in dilute hydrochloric acid, and in most of its forms is with difficulty decomposed by hot concentrated hydrochloric acid, but it dissolves completely in a strong solution of caustic potash or soda;¹ it is infusible before the blow-pipe or in ordinary furnaces.

Johnson and Blake examined microscopically twenty specimens of kaolin, pipe-, and fire-clay, and found transparent plates in all of them, and most of them appeared to consist nearly entirely of such plates. The kaolin from Diendorf (Bodenmais), Bavaria, was perhaps the most finely divided of all the white clays examined; and this, when

⁷ On Kaolinite and Pholerite; by S. W. Johnson and John M. Blake. *The American Journal of Science and Arts*, s. 2, 1867, xliii. 351. Much of the following information has been derived from this interesting paper.

⁸ *Histoire et Fabrication de la Porcelaine chinoise*; ouvrage traduit du chinois par M. Stanislas Julien; Paris, 1856, p. 250.

⁹ Dana's *System of Mineralogy*, 1868, p. 473.

¹ Johnson and Blake, *op. cit.* p. 358.

² *Histoire et Fabrication de la Porcelaine*

dusted dry upon a glass slide, seemed to be chiefly composed of masses of a white substance, which were opaque, or nearly so, in transmitted light, but when fully illuminated above and below had the translucent aspect of snow in the lump. Interspersed amongst these masses were extremely minute transparent plates of irregular rounded outline. The masses when immersed in water were almost completely resolved into similar transparent plates, most of which did not exceed 0·0001 inch in breadth. This description was found to apply to all the finer plastic clays, including the dark-coloured Stourbridge clay; a compact brownish-grey pipe-clay, from Table Mountain, Tuolumne County, California; blue fire-clay, from Mount Savage, Maryland; and various other white and coloured clays from American as well as unknown localities.

The composition of crystallized kaolinite is represented by the formula—



The composition of many kaolins or china-clays and other clays has been found to be the same as that indicated by this formula. In some of the analyses kaolin, as it occurs in nature, was operated upon, and in others washed kaolin, as prepared for the manufacture of porcelain. Forchhammer, about 1830, deduced the same formula from the results of his analytical investigation concerning china-clay, and presented it as expressive of what he termed "the normal composition of kaolin."²

COMPOSITION OF KAOLINITE PER CENT., CALCULATED FROM THE PRECEDING FORMULA.

| | |
|---------------|--------|
| Silica | 46·33 |
| Alumina | 39·77 |
| Water | 13·90 |
| | <hr/> |
| | 100·00 |

In 1862, I received from my friend, Mr. Thomas F. Evans, of Amlwch, in the Isle of Anglesea, a beautiful specimen of a white pearly crystalline mineral, which agrees in physical characters and in composition with kaolinite, and which he found near that town. A specimen of this mineral, designated "silica," and stated to have come from the copper mine of Pont-y-Gareg, Amlwch, had been previously sent by Mr. Richard Rothwell to Sir Roderick Murchison in 1859. It was immediately afterwards analysed in the Metallurgical Laboratory by C. Tooke, and found to be composed as follows:—

COMPOSITION OF KAOLINITE FROM THE ISLE OF ANGLESEY.

| | |
|-----------------------------|--------|
| Silica | 46·53 |
| Alumina | 38·93 |
| Water (by difference) | 14·54 |
| | <hr/> |
| | 100·00 |

² Ueber die Zusammensetzung der Porcellanerde und ihre Entstehung aus dem Feldspath; von G. Forchhammer. Poggendorff's Annalen, 1835, xxxv. 339.

A substance of nearly the same composition as kaolinite has been found in a variety of clay-ironstone, from Darlaston, in Staffordshire. An analysis of this substance was made by A. Dick in the Metallurgical Laboratory of the Royal School of Mines, and a report of it published in 1858.³ It occurs in veins as a white powder, accompanied with calc-spar, and it was described as a hydrated silicate of alumina. Its composition was as follows:—

COMPOSITION OF WHITE SUBSTANCE IN CLAY-IRONSTONE.

| | |
|--------------------------|-------|
| Silica | 41·78 |
| Alumina | 36·99 |
| Sesquioxide of iron..... | 4·51 |
| Lime..... | 0·48 |
| Magnesia | 0·16 |
| Water | 14·26 |

98·18

Alkalies were not sought for either in this substance or in the Anglesea kaolinite (p. 93).

The preceding evidence seems to point to an affirmative answer to the question under consideration. The facts which have been certainly established are these:—

- I. Crystallized kaolinite is a definite compound.
- II. Many kaolins and other clays are identical with crystallized kaolinite in composition.
- III. Crystallized kaolinite exists in clays which vary considerably in external characters, and occur under different geological conditions, as well as in localities widely remote from each other, *e.g.* Europe and America.
- IV. It is demonstrable that many clays consist of kaolinite intermixed with free silica and other matter.

The following evidence, on the other hand, may be adduced in favour of a negative answer:—

The china-clay of Passau was found by Forchhammer to have the formula



The composition per cent. deduced from this formula is as follows:—

COMPOSITION OF KAOLINITE PER CENT., CALCULATED FROM THE PRECEDING FORMULA.

| | |
|---------------|-------|
| Silica | 46·23 |
| Alumina | 35·27 |
| Water | 18·50 |

100·00

The relative proportions of silica and alumina often vary considerably in different clays, owing to the presence of free silica; but as no process is known, either mechanical or chemical, by which such free silica can be always perfectly separated, and a definite hydrated

³ Iron Ores of Great Britain, 1858, part 2, p. 162.

silicate of alumina uniformly obtained, it cannot be demonstrated that kaolinite exclusively forms the basis of all clays.

Silicates closely approximating to kaolinite in composition, such as pholerite and lithomarge (*Steinmark* of the Germans), have been accepted as mineral species by mineralogists of high authority. It is a question, however, as Johnson and Blake reasonably suggest, whether those minerals may not be impure kaolinite.

The mineral named halloysite only differs in composition from kaolinite in containing twice as many equivalents of water as the latter. Although certain specimens of halloysite have been found to lose half their water on drying at 100° C., and so to acquire the formula of kaolinite, yet, as Johnson and Blake remark, it cannot be assumed that this loss was due to hygroscopic water; for many substances when dried at 100° C., or below that temperature, lose part or the whole of their water of crystallization, *e. g.* selenite. Moreover, halloysite has a much lower specific gravity, and is more easily decomposed by acids than kaolinite.

The conclusion, which appears to be justified by the foregoing considerations, is, that one definite hydrous silicate of alumina, namely kaolinite, has been found in many instances to constitute the essential basis of substances usually designated clay; and in the present state of our knowledge more than this cannot confidently be asserted.

As one definite natural silicate, orthoclase or potash feldspar, can be shown to have yielded kaolin as a product of its decomposition by weathering action, or otherwise, it might reasonably have been anticipated that this product would be definite in chemical constitution; and it is easy to conceive that other silicates allied to orthoclase should also, under similar conditions of decomposition, yield the same product. But it is not to be expected that this product should be pure in a chemical sense; because the decomposition of the whole of the silicate may not have been effected, in which case the product would consist of a mixture of kaolin and original silicate not accurately separable from each other; and also because the original silicate may have been intermixed with other substances, as is feldspar with quartz and mica in granite, in which case the resulting kaolin would be associated with such substances. Hence quartz and mica usually occur in ordinary kaolin.

Clay has either remained where it was produced from its parent rock, or has been washed away and subsequently deposited in the form of beds; and in the latter case it may have become intermixed with various kinds of foreign matter. But during subsidence from a state of suspension in water, the rate of deposition varies with the specific gravity of the matter suspended and with the degree of fineness of its particles; fineness being very influential in retarding subsidence, as may be well illustrated in the precipitation, under favourable condition, of metallic gold, chloride of silver, and sulphate of baryta. Hence, when natural levigation takes place over a large area, it is easy to understand how the same continuous clayey deposit

should vary much, as well in ultimate constitution, as in degree of mechanical subdivision.

MODE OF OCCURRENCE OF KAOLINITE.—At the Einigkeit mine at Brand, near Freiberg, in Saxony, it occurs in cavities in gneiss, formed by the removal of the mica, and is the nacrite of Breithaupt.⁴ In the United States it has been met with in a cavity in a coal-seam at Summit Hill, Carbon County; in coal-mines at Tamaqua and Pottsville, both localities in Pennsylvania; and at Richmond, in Virginia, in the state of powder, much resembling to the naked eye powdered starch or wheat-flour. I have received (May 27, 1871) from my friend, Mr. Thomas F. Evans, of Amlwch, the following precise information concerning the locality and mode of occurrence of the kaolinite from the Isle of Anglesea. Between Bull Bay and a small bay a little further west, in the vicinity of Amlwch, is a place called Porth-yr-hwch, very near which a level was driven many years ago from the sea-level with the view of proving a lode of quartz-rock containing small specks and strings of copper-pyrites which show on the surface of the land above. It has been driven, as nearly as he could measure in the water—for the work has been abandoned for years—about 83 fathoms. There are near the end two or three short bits of levels driven east and west, and in one of those going west occurs the mineral in question. The fore-breast in this level is a blueish and rather hard slate, having veins of quartz running through it, and there are several small cavities which occur in the line of the quartz veins, and appear to be parts of those veins; some of the cavities are lined with a hard crystalline substance, and others contain the crystallized kaolinite. The level is driven through clay-slate, but there is a band of hard rock of an elvan character between the lode and the sea-shore. (The word *elvan* is Cornish, and is applied to particular rocks, more or less porphyritic, occurring in Cornwall.)

PLASTICITY OF CLAY.

According to Johnson and Blake, the plasticity of clay appears to be closely connected with the fineness of its particles; and in support of this statement they adduce the following facts. Of the kaolinites, which they examined, one consisting chiefly of crystal-plates, averaging 0.003 of an inch in diameter, was not plastic; a second, nearly pure, which occurred mostly in bundles of much smaller dimensions, the largest not exceeding 0.001 of an inch in diameter, was scarcely plastic; a third crystallized kaolinite was "a scarcely coherent uniplastic substance"; four kaolins, largely composed of "prismoid" crystals, were scarcely plastic, though when rubbed between the fingers they became more soapy to the touch; the kaolin of Bodenmais and other clays, in which the bundles were absent and the plates were extremely thin, were highly plastic. The first of the above-mentioned crystallized kaolinites yielded by trituration in an agate mortar a powder which, under the microscope,

⁴ Berg- und hüttenmännische Zeitung, 1865, xix. 336.

perfectly resembled the finer kaolins, and was highly plastic and sticky after having been wetted with water; and they cite the fact that two specimens of Passau kaolin, which were found to be identical in composition, differed notably from each other in degree of plasticity. They suggest that the plasticity of a clay may possibly be related to the form, and perhaps to the thickness, of the plates of the component kaolinite; and they add that they found the impurer sedimentary clays to be the most plastic, whence they infer that plasticity may in part be due to impurities.⁵ The plasticity of clay, however, must obviously be lessened by the presence of intermixed non-plastic matter, such as silica.

COMPOSITION OF FIRE-CLAY FROM VARIOUS LOCALITIES, BRITISH AND FOREIGN.

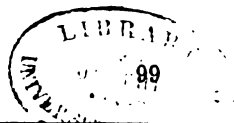
In the following tables of analyses of fire-clays I have introduced some of bad clays, in order that in respect to composition they may be compared with good clays, and so a clear indication may be afforded of the injurious ingredients of a clay. Although several of the analyses are incomplete, and in so far unsatisfactory, yet they are interesting as showing the relation between the silica and alumina.

⁵ American Journal of Science and Arts, s. 2, 1867, xliii. 358.

TABLE SHOWING THE COMPOSITION OF BRITISH FIRE-CLAYS.

| No. | Locality. | Specific Gravity. | SiO ₂ . | AlPO ₃ . | KO. | NaO. | CaO. | MgO. | FeO. | FeO ₃ . | MnO. | PO ₃ . | Water insol. | Water hygroscopic. | Organic Matter. | Miscellaneous Remarks. | Observations. |
|-----|--|-------------------|--------------------|---------------------|------|-------|----------------|-------|---------------------|--------------------|-------|-------------------|--------------|--------------------|-----------------|------------------------|--|
| 1 | {Stourbridge, Wor- {estershire . . .} | .. | 65.10 | 22.22 | 0.18 | .. | 0.14 | 0.18 | 1.92 | .. | .. | 0.06 | 7.10 | 2.18 | 0.58 | | 1. Best clay, used by Messrs. Chance for glass-pots. Brown, like a clay iron ore in colour. The silica is partly free, gritty sand being separated by washing. No sulphur was detected by boiling with nitric acid. |
| 2 | Do. do. . . | .. | 63.30 | 23.30 | .. | .. | 0.73 | .. | 1.80 | .. | .. | .. | | 10.30 | | | 2. Best clay, such as is used at the works of Messrs. Chance. |
| 3 | Congresves do. . . | .. | 57.31 | 26.58 | 0.44 | .. | 0.71 | 0.49 | 2.83 | .. | .. | trace | 8.52 | 2.26 | 0.44 | | 3. Darker than No. 1. Silica partly free. No. 1 and this clay were fashioned into small prisms with sharp edges, and exposed in the same covered crucible to a very high temperature, when No. 1 became pale brown and No. 3 grey. No. 1 is decidedly more refractory than No. 3, which became more glazed on the surface. The two trial pieces adhered firmly together where they had been in contact. The potash was determined with great care. The results were as follow :— |
| 4 | {Brierley Hill, {Staffordshire . . .} | .. | 51.80 | 30.40 | .. | trace | .. | 0.50 | 4.14 | .. | .. | .. | | 13.11 | | | By fusion with nitrate of baryta : No. 1 gave 0.20 per cent. No. 3 " 0.43 " |
| 5 | Do. do. . . | .. | 51.70 | 28.50 | .. | .. | .. | 0.86 | 5.85 | .. | .. | .. | | 12.60 | | | By hydrofluoric acid : No. 1 gave 0.16, mean 0.18 per cent. No. 3 " 0.45, " 0.44 " |
| 6 | Do. do. . . | .. | 45.27 | 28.77 | .. | .. | 0.47 | .. | 7.72 | .. | .. | .. | 9.09 | 3.00 | .. | | 8.09 grains of this clay were boiled with sulphuric acid in a platinum vessel. The insoluble residue weighed 4.985 grains, or 61.24 per cent. The total amount of silica found by fusion with alkaline carbonate was 57.31, so that the decomposition of the clay by sulphuric acid was not complete. The 4.985 grains of residue were boiled with a solution of carbonate of soda and a little caustic potash during two days: the insoluble residue weighed 2.38 grains, or 29.41 per cent., which in great measure was silica in the state of sand. |
| 7 | {Glasco, near {Tamworth . . .} | .. | 50.20 | 32.59 | 2.32 | .. | 0.36 | 0.44 | .. | 3.52 | trace | .. | | | .. | | |
| 8 | Do. do. . . | .. | 49.40 | 32.80 | 2.24 | .. | not determined | 0.43 | .. | 3.97 | trace | .. | 9.84 | .. | .. | | |
| 9 | {Stannington, near {Sheffield . . .} | .. | 48.04 | 34.47 | 1.94 | .. | 0.66 | 0.45 | .. | 3.06 | .. | .. | 11.16 | .. | .. | | |
| 9A | {Edenmont, near {Sheffield . . .} | .. | 45.73 | 34.14 | 0.45 | .. | 0.79 | 0.74 | 1.76 {FeO 0.77 } | trace | trace | .. | 10.17 | 4.45 | 0.70 | trace of titanio acid | |
| 10 | Elmsor, near Derby. | .. | 48.08 | 36.89 | 1.88 | .. | 0.55 | trace | .. | 2.26 | .. | .. | 10.97 | .. | .. | | |

COMPOSITION OF FIRE-CLAY.



| | | | | | | | | | | | | | | | |
|----|-------------------------------------|-------|-------|-------|------|---|------|------|------|------|--------|---|------|--|-------------------------------|
| 11 | Newcastle-on-Tyne. | 2.619 | 55.50 | 27.75 | 2.19 | 0.44 with Cl and SO ₂ | 0.67 | 0.75 | .. | 2.01 | .. | 10.53 with traces of organic matter | .. | .. | traces of sul- phuric acid |
| 12 | {Teignmouth, De- vonshire . . .} | .. | 53.06 | 29.38 | 2.29 | .. | 0.43 | 0.02 | 2.37 | .. | 10.27 | 2.56 | .. | .. | .. |
| 13 | Poole, Dorsetshire . | .. | 48.99 | 32.11 | 3.31 | .. | 0.43 | 0.23 | 2.34 | .. | 9.63 | 2.33 | .. | .. | .. |
| 14 | Dowlais, South Wales | .. | 67.12 | 21.18 | 2.02 | .. | 0.32 | 0.84 | .. | 1.86 | .. | 4.83 | 1.39 | 0.90 with a little CO ₂ | .. |
| 15 | Do. do. . | .. | 44.25 | 34.76 | 1.68 | .. | 0.34 | 1.18 | .. | 3.41 | traces | 8.56 | 2.89 | 3.17 | .. |
| 16 | Do. do. . | .. | 53.06 | 28.13 | 4.19 | .. | 0.17 | 1.20 | .. | 2.48 | .. | 5.82 | 2.20 | 2.82 | .. |
| 17 | Do. do. . | .. | 47.29 | 33.07 | 2.13 | .. | 0.45 | 1.06 | .. | 2.52 | .. | 9.07 | 2.19 | 2.63 | .. |
| 18 | Do. do. . | .. | 46.26 | 32.14 | 2.11 | .. | 0.73 | 1.21 | .. | 2.99 | .. | 8.79 | 2.77 | 3.46 | .. |
| 19 | Do. do. . | .. | 58.10 | 28.59 | 1.21 | .. | 0.40 | 0.99 | .. | 2.97 | .. | 7.57 | 1.41 | 1.21 | .. |
| 20 | Do. do. . | .. | 53.99 | 28.66 | 1.76 | .. | 0.31 | 0.88 | .. | 3.27 | .. | 7.41 | 1.52 | 2.46 | .. |
| 21 | Do. do. . | .. | 57.10 | 26.77 | 1.86 | .. | 0.28 | 1.07 | .. | 3.10 | .. | 6.44 | 1.76 | 1.89 | .. |
| 22 | Ireland | .. | 79.40 | 12.25 | .. | .. | 0.50 | .. | .. | 1.30 | .. | 5.20 | .. | .. | .. |

4. This clay was tried by Ruel, of Holborn, refiner and crucible-maker, and pronounced by him to be of first-rate quality.

7. 8. This clay is made into fire-bricks by Messrs. Gibbs, Canning & Co. We have used this clay during many years at the School of Mines to make small crucibles with, for the assaying of iron-ores by the Swedish method. The iron existed both as protoxide and sesquioxide, but the proportions of the two oxides were not ascertained. My friend, M. Léon Arnoux, of Messrs. Minton and Co.'s China-works, informs me that it is extremely good for saggers.

9. 10. I received specimens of these clays from the late Mr. E. F. Sanderson, of Sheffield, by whom they were used for crucibles. They were weighed for analysis after desiccation at 100° C.

9A. Designated "Pot Clay," and used in making crucibles for melting cast-iron. It is said to be excellent in quality for that purpose. The air-dried clay lost 1.01 per cent. in weight by desiccation at 100° C.

11. Colour grey, streak dull, very soapy to the touch. It constitutes usually the basement of each coal-seam. From Blaydon Burn Colliery in Tyne-side. It is used for fire-bricks.

12. Light brownish-grey, with small dark particles (lignite) diffused through it. Used in admixture for Cornish crucibles. This clay occurs at Bovey-Tracey. In admixture with lignite, and is called Teignmouth clay from its being shipped at that port.

13. Greyish white, soapy to the touch. Used in admixture for Cornish crucibles.

14-21. All from Downais. The local name of the coal-seams with which the clay is associated, is dated under each number. No. 14 is considered the best fire-clay at Downais. Blasen Rhos, three coals and clay. No. 16. Not generally considered good as a fire-clay. From the

TABLE SHOWING THE COMPOSITION OF BRITISH FIRE-CLAYS—continued.

| No. | Locality. | Specific Gravity | SiO ₂ | AlPO ₃ | K ₂ O | Na ₂ O | CaO | MgO | FeO | Fe ₂ O ₃ | MnO | PO ₅ | Water combined. | Water hygroscopic. | Organic Matter. | Miscellaneous Remarks. | Observations. |
|-----|--|------------------|------------------|-------------------|------------------|-------------------|------|------|------|--------------------------------|-----|-----------------|-----------------|--------------------|-----------------|--|---------------|
| 23 | Ireland | .. | 74.44 | 19.04 | 2.07 | .. | 0.45 | 0.27 | .. | 0.61 | .. | .. | 3.71 | .. | .. | level Tomo. No. 16. This clay melted down on the bridge of a boiling furnace. Red coal. 17. Buen Rhua. Little Vein. 18. Coal clod. 19. Pantywalh. 20. Lower 4 feet 2. 21. Little Pina. 22. Small crucibles made of this clay were kept for hours with melted steel in them without in the least changing form. 23. I believe this clay was from Howth, near Dublin. 24, 25. Said to be the finest china-clay in Cornwall. The two analyses are of the same clay by different men. 26. Lathia was detected by the spectroscope. | |
| 24 | Cornwall | .. | 46.32 | 39.74 | .. | .. | 0.36 | 0.44 | 0.27 | .. | .. | .. | 12.67 | .. | .. | "some alkali" is included in the water | |
| 25 | Do. | .. | 46.29 | 40.09 | .. | .. | 0.50 | .. | 0.27 | .. | .. | .. | 12.67 | .. | .. | • dried at 100° C. | |
| 26 | { Do. 3 miles north } { of St. Austell. } | .. | 47.76 | 38.11 | 0.73 | .. | 0.16 | 0.02 | 0.09 | .. | .. | .. | 12.64 | .. | traces | dried at 100° C. | |

1. By C. Tockey.—2. By E. Cowper.—3. By C. Tockey.—4. 5. By T. H. Henry, communicated to the Author.—6. By J. Spiller.—7. By J. Spiller.—8, 9, 10. By Burbridge Hambly.—9A. By W. J. Ward.—11. By Hugh Taylor, Edinb. New Phil. Journ. 1. 162.—12, 13. By W. Weston.—14-21. By Edward Riley, formerly chemist at Dowling, communicated to the Author.—22. By T. H. Henry, communicated to the Author.—23. By J. Spiller.—24. By R. A. Cooper.—25. By J. Brown, Phil. Mag. 1847, xxxi. 439.—26. By W. J. Ward.—Rom. 1, 3, 7, 8, 9, 10, 12, 13, 23, and 26, were analysed in the Laboratory at the Royal School of Mines.

GEOLOGICAL POSITION OF THE CLAYS IN THE PRECEDING TABLE.— [that numbered 12 is of Miocene age; and the remaining ones, The clays numbered 1, 2, 3, 4, 5, 6, 7, 8, 9, 9A, 10, 11, 14, numbered 13, 22, 23, 24, 25, 26, are china or pottery clays, 15, 16, 17, 18, 19, 20, 21, are all from the Coal-measures;] resulting from the decomposition of granitic feldspar.

TABLE SHOWING THE COMPOSITION OF FOREIGN FIRE-CLAYS.

| No. | Country. | Silica. | Alumina. | Alkalies. | Lime. | Magnesia. | Sesquioxide of iron. | Water combined. | Water hygroscopic. | Miscellaneous Observations and Particular Localities. |
|-----|---------------------|---------|----------|-----------|--------|-----------|----------------------|-----------------|--------------------|--|
| 1 | France | 63.67 | 27.45 | .. | 0.55 | traces | 0.15 | 8.64 | 1.27 | 1. Yellowish. At the highest temperature of the Sèvres porcelain kiln it only frits on the surface. Boelen (Ardennes). |
| 2 | Do. | 69.43 | 18.00 | .. | 2.00 | 3.27 | 0.95 | 6.38 | 2.24 | 2. Greyish-brown. Boulogne (Pas-de-Calais). |
| 3 | Do. | 44.50 | 53.00 | traces | 1.34 | 0.60 | 1.91 | 16.48 | 12.87 | 3. Grey plastic clay, above the chalk. Used for saggars for porcelain. Condé, near Houdan (Seine-et-Oise). |
| 4 | Do. | 60.60 | 26.39 | .. | 0.84 | .. | 2.50 | 9.20 | .. | 4. Infusible at the highest temperature of the Sèvres porcelain kiln. White plastic clay, occurring in the upper fresh-water beds of the Paris basin. Dourdan (Seine-et-Oise). |
| 5 | Do. | 49.20 | 34.00 | .. | .. | .. | .. | 16.40 | .. | 5. White plastic clay. Used for crucibles employed in the treatment of ores of antimony. Ecuisteres (Allier). |
| 6 | Do. | 46.58 | 38.10 | .. | traces | .. | .. | 14.50 | 0.42 | 6. Used for saggars for porcelain. Gajac (Landes). |
| 7 | Do. | 66.10 | 19.80 | .. | .. | .. | 6.80 | 7.50 | .. | 7. Sandy yellowish clay. Used for fire-bricks. Hayange (Moselle). |
| 8 | Do. | 55.40 | 26.40 | .. | .. | .. | 4.20 | 12.00 | .. | 8. Dirty yellowish-white clay. Used for glass-pots. La Bouchade, near Montluçon (Allier). |
| 9 | Do. | 52.55 | 26.50 | .. | 3.00 | 1.50 | 0.55 | 15.00 | 1.55 | 9. Vined plastic clay. Used for porcelain saggars at Limoges. Malais, near Limoges (Haute-Vienne). |
| 10 | Do. | 52.10 | 36.00 | .. | 5.00 | 2.00 | 1.80 | .. | .. | 10. Whittish plastic clay. Used for fire-bricks and porcelain saggars at Sèvres. Brevaux (Seine-et-Oise). |
| 11 | Do. | 42.00 | 38.96 | .. | 1.04 | 0.17 | 0.85 | 16.96 | 2.27 | 11. Reddish. Used for porcelain saggars at Sèvres. Retourneloup (Seine-et-Marne). |
| 12 | Do. | 58.76 | 28.10 | traces | traces | 2.51 | 2.50 | 11.05 | 1.45 | 12. Reddish, with scales of mica. Used for crucibles in which cast-steel is melted at St. Etienne. Savasse (Ardèche). |
| 13 | Hessen-Cassel | 47.50 | 34.37 | traces | 0.50 | 1.00 | 1.24 | 14.00 | 0.43 | 13. Greyish. Used for Hessian crucibles. Grosse-Almerode, Hessen-Cassel. |
| 14 | Bavaria | 45.79 | 28.10 | .. | 2.00 | .. | 6.55 | 16.50 | 0.05 | 14. Deep grey. Used for Poesen crucibles. Schildorf, near Passau. |
| 15 | Saxony | 61.52 | 20.92 | traces | 0.02 | 4.97 | 0.50 | 11.70 | 2.70 | 15. Blackish, contains quartz. Used for porcelain saggars in the Meissen porcelain manufactory. Losdahn, near Meissen. |
| 16 | Bohemia | 58.39 | 27.94 | .. | 2.74 | 1.00 | traces | 10.00 | 0.49 | 16. White, very soft to the touch. Below the lignite. Used for saggars at Elbogen. Thienberg, near Carlsbad. |
| 17 | Austria | 65.60 | 20.75 | traces | 1.65 | traces | 2.00 | 10.00 | 1.00 | 17. Pale dirty green, mixed with ferruginous spots. Used for porcelain saggars at Vienna. Gottweith, near Krems. |
| 18 | United States | 72.33 | 16.75 | .. | 2.00 | 0.07 | 1.29 | 6.84 | 1.14 | 18. Greenish-grey, mixed with red spots. Used for porcelain saggars and glass-pots. Delaware, 7 miles south of Newcastle. |

1, 2, 3, 4, 6, 9, 11, 12, 13, 14, 15, 16, 17, 18, by Salvétat. 5, 7, 8, by Berthier. 10, by Bunsen. Traité des Arts céramiques. Brongniart, Atlas, 1844.

INFLUENCE OF ALKALI IN FIRE-CLAYS.—The influence of alkali in promoting the fusibility of clay is well shown by the analysis No. 16 in the foregoing table of British fire-clays (p. 99); and, in further illustration, the following analysis is introduced of a red clay from Watcombe, near Torquay, in South Devon.⁶ When this clay was heated in a crucible in an ordinary assay-furnace, it melted into black glass.

COMPOSITION OF WATCOMBE CLAY.

| | |
|---------------------------|--------|
| Silica | 57·83 |
| Alumina..... | 20·55 |
| Potash | 3·87 |
| Soda | 0·56 |
| Lime | 1·68 |
| Magnesia | 0·97 |
| Sesquioxide of iron | 7·75 |
| Oxide of manganese..... | traces |
| Carbonic acid | 0·90 |
| Water, combined | 4·39 |
| Water, hygroscopic | 2·13 |
| Organic matter..... | traces |
| | <hr/> |
| | 100·63 |

IRON-PYRITES IN FIRE-CLAYS.—The analysis, No. 9A in the preceding table of British fire-clays (p. 98), is noticeable on account of the iron-pyrites which the clay contains. The presence of this substance is said to be confined to one part of the mine where the clay deposit is intersected by a fault. The quantity of sulphur in the pyrites is too small to produce any appreciable effect on metal melted in crucibles made of this clay, that is, provided the pyrites is uniformly diffused through the mass. When the crucible is heated to redness, half the sulphur will be evolved, with the formation of protosulphide of iron; and there will probably be always sufficient atmospheric oxygen within the crucible to oxidize the protosulphide near the surface and expel the sulphur therefrom.

TITANIC ACID IN FIRE-CLAYS.—Riley has specially investigated this subject, and announced that he has detected it in every specimen of fire-clay, or brick made of such clay. The largest amount, 1·05 per cent., was found in a Stourbridge fire-brick, and the smallest amount, quantitatively determined, 0·42 per cent., in a Newcastle-on-Tyne fire-brick.⁷ Titanic acid, even in the maximum proportion above-mentioned, would, probably, not affect the quality of fire-clay in an appreciable degree. Further remarks on titanic acid will be found in this volume under the head of Hessian Crucibles.

⁶ The analysis was made in my laboratory, by W. J. Ward.
⁷ Quart. Journ. of the Chem. Soc. 1862, xv. 311.

GRAPHITE, BLACK-LEAD, OR PLUMBAGO.

Graphite is one of the allotropic states of carbon, or carbon crystallized in the rhombohedral system of Miller. It occurs in various parts of the world in association with igneous and metamorphic rocks, and is also artificially produced in the smelting of iron. Graphitic carbon, or pure graphite, neither melts, softens, nor is in any way changed at the highest temperatures of furnaces, provided access of oxygen be prevented; and it burns very slowly even when strongly heated in atmospheric air. On account of these properties it is a valuable material for crucibles. Native graphite varies considerably in purity and state of aggregation. It is unctuous to the touch, and when rubbed between the fingers produces a mark, which can only be imitated with a few other substances, as, for example, sulphide of molybdenum and micaceous iron-ore.⁸ Graphite suitable for the manufacture of the best black-lead pencils is of rare occurrence, and, consequently, fetches a high price. No graphite has been so much in request for this purpose as that of Borrowdale in Cumberland; but graphite adapted to the manufacture of crucibles may be procured in abundance in various localities at a moderate price. It is the peculiar state of aggregation which gives value to the Borrowdale graphite, and not its purity; for, according to Karsten, it leaves on combustion not less than 13·3 per cent. of ash; whereas some of the Ceylon graphite, which is of comparatively small value for pencils, contains only traces of foreign matter.⁹ The specific gravity of the native mineral may vary much even in the same piece. Thus, in different parts of one piece, of 8 or 9 cubic inches in bulk, Karsten found the specific gravity to vary from 2·226 to 2·419, a difference of about 0·2, which corresponds to a difference in the amount of foreign matter, as the two pieces yielded respectively 13·10 and 14·27 per cent. of ash.

The suitability of graphite for crucibles depends, not only on the nature and proportion of the associated foreign matter, but also on the state of aggregation of the graphitic carbon; and, by variation in the latter respect, may probably be explained the fact, communicated to me by a high practical authority, that several native graphites are valueless for crucibles. This is a question which must be decided by an actual trial.¹

⁸ On once visiting certain metallurgical works, I saw a considerable quantity of this kind of iron-ore, which had been unwittingly purchased for plumbago with a view to its use in lubrication.

⁹ Dumas and Stas, *Ann. de Chim. et de Phys.* s. 3, 1841, i. 26.

¹ Berthelot has found that *graphitic oxide* prepared with graphite from dif-

ferent localities varies somewhat in physical characters. His researches upon the subject have yielded results, which are interesting and important in a scientific point of view, and may possibly be useful to manufacturers of black-lead crucibles. They will be found in the *Ann. de Chim. et de Phys.* s. 4, 1873, xxx. 424 *et seq.*

It should be borne in mind that, as the proportion of carbon may vary considerably even in different portions of graphite from the same locality, it is desirable that it should be ascertained; and this may be readily done by incinerating the graphite thoroughly and weighing the residue of ash. What it thus loses in weight may generally be estimated as carbon. Incineration may be conveniently effected in a platinum crucible at a good red-heat in a muffle, the operation being prolonged until the weight of the residue remains constant.

COMPOSITION OF GRAPHITE FROM VARIOUS LOCALITIES.

In the following table the composition of graphite from various localities is presented; and towards the end of it are given, for the sake of comparison, analyses of graphite produced at some French ironworks, and of the carbon which accumulates as a solid deposit on the internal surface of gas-retorts. I have used this gas-retort carbon with success, more than 20 years ago, in the manufacture of carbon crucibles; and it is now employed in certain kinds of voltaic batteries, and for the carbon points of the electric light. The mode of applying this material will be described further on, under the head of lining crucibles with carbon.

COMPOSITION OF GRAPHITE.

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TABLE SHOWING THE COMPOSITION OF GRAPHITE FROM VARIOUS LOCALITIES.

The name of the analyst is inserted within parentheses under the locality.

| Locality. | Specific Gravity. | Per cent. | | | Composition of Ash per cent. | | | | |
|---|-------------------|------------------|---|------------|------------------------------|----------|---|----------------------------|--------------------------|
| | | Volatile Matter. | Carbon. | Ash. | Silica. | Alumina. | Sesquioxide of Iron. | Lime and Magnesia. | Alkalies and Loss. |
| England, Cumberland, very fine specimen... (Mene.) ¹ | 2.8455 | 1.10 | 91.55 | 7.36 | 52.5 | 28.3 | 12.0 | 6.0 | 1.2 |
| England, Cumberland, commercial sample in pieces | 2.5857 | 2.62 | 84.38 | 13.00 | 62.0 | 25.0 | 10.0 | 2.6 | 0.4 |
| England, Cumberland, commercial sample in powder. (Mene.) | 2.4092 | 6.10 | 78.10 | 15.80 | 58.5 | 30.5 | 7.5 | 3.5 | 0.0 |
| England, Cumberland, ordinary specimen... (Mene.) | 2.2379 | 3.10 | 80.85 | 16.05 | .. | .. | .. | .. | .. |
| England, Cumberland, Borrowdale (Karsten.) ² | .. | .. | Carbon and vol. matter (vol. abbreviation of volatile) 86.7 | 19.3 | 36.5 | 26.7 | (MnO ²) 1.8 and a trace of chromium 18.1 | Lime a trace, magnesia 2.7 | (TiO ²) 14.2 |
| Canada, Buckingham (Mene.) | 2.2863 | 1.82 | 78.48 | 19.70 | 65.0 | 25.1 | 6.2 | 0.5 | 1.2 |
| India, Himalaya (Prinsep.) | .. | .. | 71.6 | 28.4 | .. | .. | .. | .. | .. |
| Ceylon, crystallized (Mene.) | 2.3501 | 5.10 | 79.40 | 15.50 | .. | .. | .. | .. | .. |
| Ceylon, crystallized (Prinsep.) | .. | .. | Carbon and vol. matter 94.0 to 98.8 | 6.0 to 1.2 | .. | .. | .. | .. | .. |

¹ All the analyses by M. Ch. Mene are taken from a table drawn up by him in the Comptes rendus for 1867, liv. 1092. In these analyses the column on the right of that with the heading "Alumina" is headed "Fer;" it may be inferred that in the accompanying table the same oxide is intended, and it is not stated whether metallic iron or oxide of iron is meant, though

² Archiv, 1st series, xii. 93.

TABLE SHOWING THE COMPOSITION OF GRAPHITE FROM VARIOUS LOCALITIES—continued.
The name of the analyst is inserted within parentheses under the locality.

| Locality. | Specific Gravity. | Per cent. | | | Composition of Ash per cent. | | | | |
|---|-------------------|------------------|-----------------------------|-------|------------------------------|----------|----------------------|--------------------|--------------------|
| | | Volatile Matter. | Carbon. | Ash. | Silica. | Alumina. | Sesquioxide of Iron. | Line and Magnesia. | Alkalies and Loss. |
| Ceylon, crystallized | .. | .. | Carbon and vol. matter 96.1 | 3.9 | .. | .. | .. | .. | .. |
| Ceylon, (Knapp.) [*] | 2.2659 | 5.20 | 68.30 | 26.50 | 50.3 | 41.5 | 8.2 | 0.0 | 0.0 |
| Ceylon, commercial (Mène) | | | Carbon and vol. matter 63.8 | | | | | | |
| Ceylon, unpurified | .. | .. | Carbon and vol. matter 81.5 | 37.2 | .. | .. | .. | .. | .. |
| Ceylon, coarsely purified | .. | .. | | 18.5 | .. | .. | .. | .. | .. |
| South Australia, Spencer's Gulf | 2.3701 | 2.15 | 25.75 | 72.10 | .. | .. | .. | .. | .. |
| South Australia, Spencer's Gulf | 2.2852 | 3.00 | 50.80 | 46.20 | 63.1 | 28.5 | 4.5 | .. | 3.9 |
| France, Pissie, Hautes-Alpes | 2.3280 | 2.17 | 72.68 | 25.15 | .. | .. | .. | .. | .. |
| France, Pissie, Hautes-Alpes | 2.4572 | 3.20 | 59.67 | 37.13 | 68.7 | 68.7 | 8.1 | 1.5 | 0.9* |
| France, Kaiserberg, Haut-Rhin | .. | .. | Carbon and vol. matter 42.2 | 57.8 | | | | | |
| France, (Fertil.) ^y | 2.2029 | 0.28 | 92.00 | 7.72 | .. | .. | .. | .. | .. |
| France, Brusin, Francheville, Rhone | .. | 0.14 | 93.21 | 6.65 | .. | .. | .. | .. | .. |
| France, Sainte-Paule, Rhone | 2.3656 | 0.17 | 92.50 | 7.33 | .. | .. | .. | .. | .. |

| | 2·1050 | 0·13 | 91·00 | 5·67 | .. | .. | .. | .. | Trace of pyrites |
|---|--------|------|-----------------------------------|-------|------|------|------|--------------|---------------------|
| France, Vaucluse, Rhodan. (Méne.) | 2·1050 | 0·13 | 91·00 | 5·67 | .. | .. | .. | .. | .. |
| Sweden, Fagerita | 2·1002 | 1·55 | 87·65 | 10·80 | 58·0 | 31·5 | 7·2 | 0·5 | 2·2 |
| Russia, Alibort mts, Oural. (Méne.) | 2·1759 | 0·72 | 94·03 | 5·25 | 64·2 | 24·7 | 10·0 | 0·8 | 0·8 |
| Bavaria, Passau, commercial sample in powder (Méne.) | 2·3108 | 4·20 | 73·65 | 22·15 | 69·5 | 21·1 | 0·5 | 2·0 | 1·9 |
| Bavaria, Passau, commercial sample in powder (Méne.) | 2·3032 | 7·30 | 81·08 | 11·62 | 53·7 | 35·6 | 6·8 | 1·7 | 2·2 |
| Bavaria, Hafnerzell, near Passau (Berthier.) ^a | .. | .. | Carbon and vol. matter 34·9 | 65·1 | 63·3 | 22·6 | 12·6 | (MgO) 1·5 | .. |
| Bavaria, Hafnerzell, near Passau (Knapp.) | .. | .. | Carbon and vol. matter 47·1 | 52·9 | .. | .. | .. | .. | .. |
| Bavaria, Hafnerzell, near Passau, commercial sample. (Ragaky.) ^b | .. | .. | Carbon and vol. matter 42·0 | 58·0 | 45·5 | 43·3 | 11·2 | .. | .. |
| Bohemia, Schwarzbach | 2·3433 | 1·05 | 88·05 | 10·90 | 62·0 | 28·5 | 6·3 | 1·5 | 1·7 |
| Bohemia, Schwarzbach, first quality | .. | .. | Carbon and vol. matter 87·5 | 12·5 | 40·8 | 48·8 | 9·6 | (CaO) 0·8 | .. |
| Bohemia, Schwarzbach, commercial sample in powder. (Méne.) | 2·2279 | 2·85 | 90·85 | 6·30 | .. | .. | .. | .. | .. |
| Bohemia, Muggau, commercial sample in powder. (Méne.) | 2·1197 | 4·10 | 91·05 | 4·85 | 61·8 | 28·5 | 8·0 | 0·7 | 1·0 |
| Bohemia, Prague (Méne.) | 2·3309 | 2·07 | 82·68 | 15·25 | .. | .. | .. | .. | .. |

^a German translation of the first edition of this volume, p. 231.

^b Jahrbuch der k.-k. geolog. Reichsanstalt, 1854, p. 863.

^c Berthier, Traité des Essais, i. 50.

^d Kennigott, Uebersicht, 1854, p. 119. Published 1856.

^e Ibid.

^f There is an obvious typographical error in these numbers which exists in the original, and which I am unable to correct.

TABLE SHOWING THE COMPOSITION OF GRAPHITE FROM VARIOUS LOCALITIES—continued.

The name of the analyst is inserted within parentheses under the locality.

| Locality. | Specific Gravity. | Per cent. | | | Composition of Ash per cent. | | | | |
|---|-------------------|------------------|---------------------------------|-------|------------------------------|----------|----------------------|--------------------|--------------------|
| | | Volatile Matter. | Carbon. | Ash. | Silica. | Alumina. | Sesquioxide of Iron. | Lime and Magnesia. | Alkalies and Loss. |
| Moravia, Alstadt | 2.3272 | 1.17 | 87.58 | 11.25 | .. | .. | .. | .. | .. |
| (Mène.) | | | Carbon and volatile matter 43.0 | | | | | | |
| Moravia, Hafnealuden | .. | .. | 57.0 | 12.2 | 86.4 | 12.2 | 1.4 | .. | .. |
| (Ragsky.) | | | | | | | | | |
| Lower Austria, Zaptan | 2.2179 | 2.20 | 90.63 | 7.17 | 55.0 | 30.0 | 14.3 | 0.0 | 0.7 |
| (Mène.) | | | | | | | | | |
| Brazil, Ceara | 2.3865 | 2.55 | 77.15 | 20.30 | 79.0 | 11.7 | 7.8 | 1.5 | 0.0 |
| (Mène.) | | | | | | | | | |
| Madagascar | 2.4085 | 5.18 | 70.69 | 24.13 | 59.6 | 59.6 | 6.8 | 1.2 | 0.6 ¹ |
| (Mène.) | | | | | | | | | |
| Artificial, from Creusot Ironworks, France | 2.5923 | .. | 90.80 | 9.20 | 22.5 | 17.5 | 37.5 | 25.5 | 0.5 |
| (Mène.) | | | | | | | | | |
| Artificial, from Creusot Ironworks, France | 2.3981 | 0.30 | 81.90 | 17.80 | 42.5 | 9.0 | 8.0 | 40.5 | 0.0 |
| (Mène.) | | | | | | | | | |
| Artificial, from Ironworks, Vienne, France | 2.5890 | 0.15 | 88.30 | 11.55 | .. | .. | .. | .. | .. |
| (Mène.) | | | | | | | | | |
| Artificial, from Ironworks, Givors, France | 2.4571 | .. | 84.70 | 15.30 | 55.9 | 15.5 | 12.0 | 15.5 | 0.1 |
| (Mène.) | | | | | | | | | |
| Artificial, from Ironworks, Tarrenoire, France. | 2.4909 | .. | 83.50 | 16.50 | 50.0 | 16.0 | 10.5 | 20.0 | 3.5 |
| (Mène.) | | | | | | | | | |
| Artificial, from gas-retorts | 1.8853 | 0.25 | 95.25 | 4.50 | 72.0 | 24.3 | 3.0 | 0.0 | 0.7 |
| (Mène.) | | | | | | | | | |
| Artificial, from gas-retorts | 1.6980 | 0.10 | 90.60 | 9.30 | 64.8 | 33.0 | 2.0 | 0.0 | 0.2 |
| (Mène.) | | | | | | | | | |

* Kennigott, Uebersicht der Resultate mineralogischer Forschungen, for 1854. p. 119. Published 1856.

¹ There is an obvious typographical error in these numbers which exists in the original, and which I am unable to correct.

SIBERIAN GRAPHITE.

In the Russian department of the International Exhibition held in London in 1862, there was an interesting display of specimens and articles of graphite, the produce of the Mount Alexeyef Mine, belonging to Michael K. Sidoroff, Lower Tongooska river, Siberia. Specimens of this graphite were supplied to me by Mr. Brandt, and examined in my laboratory at the Royal School of Mines by C. Tookey, lately Assayer of the Imperial Mint at Osaka in Japan. The following complete analysis of one specimen was made:—

COMPOSITION OF SIBERIAN GRAPHITE.

| | |
|-------------------------|--------|
| Carbon | 86.56 |
| Silica | 3.86 |
| Alumina..... | 3.04 |
| Protoxide of iron | 2.84 |
| Lime | 0.20 |
| Magnesia | 1.70 |
| Water..... | 2.70 |
| | <hr/> |
| | 100.40 |

The carbon was estimated by the ordinary method of organic analysis in a current of oxygen. Hydrochloric acid dissolved out of the graphite a considerable quantity of alumina and oxide of iron, and a copious blue precipitate was produced in the solution by the addition of ferricyanide of potassium (red prussiate of potash). Water, neutral to test-paper, was evolved on heating this graphite.

Three other specimens of this graphite yielded 9.04, 12.48, and 17.32 per cent. of ash, respectively.

The graphite is massive, finely laminated, soft, earthy, dull, but immediately acquires a bright lustre by burnishing. It is stated to occur in granite; and a specimen of it, analysed by N. Kokscharow, contained as much as 94.8% of carbon.

The graphite from Alibert's mine, Mariinskoi, Irkutsk, is described as compact, fibrous, columnar, reniform, or with indistinct tabular crystallization.² A large mass of graphite, having the structure of wood, has been found in this mine.³ In five analyses of it, by four different persons, the proportion of carbon was found to range from 83.755% to 94.77%, and the ash from 3.213% to 15.111%; in three of the analyses water appears as a constituent, varying in quantity from 0.888% to 3.77%; and that which contained most ash, viz. 15.111%, contained least water, viz. 0.888%.⁴

² Kennigott, Uebersicht der Resultate mineralogischer Forschungen, for 1862–1863, p. 263. Published 1868.

³ Dana's System of Mineralogy, 1868, p. 25.

⁴ Kennigott, *loc. cit.*

CRUCIBLES.

The term crucible is generally applied to earthenware vessels in which metals or other substances are heated in furnaces; but the term is not restricted to vessels of earthenware: it is extended to all open-mouthed movable vessels, of whatsoever material composed, in which substances are exposed to high temperatures. Thus, there are crucibles of graphite, iron, platinum, and lime. In English it is usual to confine the use of the term crucible to vessels which can be conveniently handled by means of tongs or forceps, and which are not intended to remain as fixtures in a furnace during any length of time. In French the term crucible (*creuset*) is applied not only to movable vessels, but even to the hearths of blast-furnaces. It has been asserted that the origin of the word crucible is due to the superstitious practice of the alchemists of marking these vessels with the sign of the cross; and, as Latin was the language in which they wrote, the word is supposed to have been derived from *cruz*, *crucis*,⁵ whence the expression *crucial experiment*. The use of superstitious signs is not yet extinct with physicians, for in their prescriptions the prolonged tail of the letter R, which is intended as an abbreviation for *Recipe*, is a relic of the astrological symbol of Jupiter.⁶ The word crucible has been spelt *chrysible*,⁷ which suggests a possible relation to χρυσός, the Greek word for gold, as earthen pots were much used by alchemists in their attempts to produce that precious metal by transmutation, and by others for refining and melting it. But the best modern authorities maintain that the words *crucible*, *crook*, *cruse*, *cruet*, and *creuset* have the same root.⁸

The qualities required in crucibles may be thus enumerated:—

They should all resist a high temperature without melting or softening in a sensible degree, and should not be so tender, while hot, as to be liable to crumble or break when grasped with tongs.

In some cases they should resist sudden and great alterations of temperature, so that they may be plunged while cold into a nearly white-hot furnace without cracking, while in other cases it is only necessary that they should resist a high temperature after having been gradually heated.

They may occasionally be required to withstand the corrosive action and permeation of such matters as molten oxide of lead.

In special cases, the material of which they are composed, must not contain any ingredient that would act chemically upon the substances heated in them: thus, carbonaceous matter should not be one of their constituents when they are used in the heating of such

⁵ Johnson's Dictionary, London, 1805, 9th ed. Longman and Co. "Crucible—a chymist's melting-pot, made of earth: so called because they were formerly marked with a cross."

⁶ Pharmacologia. By J. A. Paris, M.D., F.R.S., 8th ed., 1833, p. 13.

⁷ The Art of Glass, by Antonio Neri. Translated into English. London, 1662, p. 169.

⁸ Information on this point will be found in Wedgwood's Dictionary of English Etymology, 2nd ed. 1872, p. 184.

oxidized matters as carbon would reduce, and reduction is not desired; or in the fusion of steel when it is necessary that its proportion of carbon should not be increased. These crucibles are, however, occasionally used for melting steel in, when, in order to keep the proportion of carbon constant, malleable iron must be added in such quantity as can only be ascertained by experiment.

Crucibles vary much in chemical constitution, as well as in other respects; and they must, therefore, be specially selected according to the purposes for which they are intended.

EARTHEN OR CLAY CRUCIBLES.

These crucibles are made of fire-clay intermixed with silica, burnt clay, or other matter, which is either infusible or highly refractory. When clay is dehydrated by heat, it contracts considerably; and even after the complete expulsion of its water of combination, it may suffer much further contraction by exposure to a higher temperature. Wedgwood, in the construction of his pyrometer, availed himself of the property which clays thus possess of shrinking or contracting in a degree corresponding to the degree of heat to which they are subjected. In proportion to the amount of contraction, which a clay crucible suffers when heated, will be its liability to crack. In order to counteract, as far as practicable, the evil due to contraction, clay crucibles are made of a mixture of clay and of some other substance, which either expands somewhat by heat, or at least does not contract in a sensible degree. The other qualities required in the substance added are infusibility at high temperatures, and freedom from any tendency to melt the clay, conditions well fulfilled by highly burnt fire-clay, silica, and carbon in the state of graphite or coke.

The unburnt clay must be reduced to powder by grinding. Complete disintegration may be effected by leaving the clay freely exposed to the action of the weather especially during winter.

The plasticity of clay is said to be much increased by weathering action. Moreover, exposure of fire-clay to the action of the weather is said to be important and most beneficial, as the bad portions become thereby detached from the good clay, so that they may be seen and picked out with ease.*

The burnt clay is generally prepared by grinding crucibles which have been used, or, still better, old fragments of glass-pots which have been exposed to a high temperature during a long time. Before grinding up the fragments or potsherds, any vitrified matter adhering to their surface should be carefully chipped off. The size of the particles of burnt pot is a matter of importance; and Brongniart insists that variation in their size is an advantage. Failing these materials, fire-clay may be burnt expressly for the purpose. The proportion of burnt to raw clay may be altered according to circumstances.

* Cowen on Fire-clay Goods, Civil Engineer and Architect's Journal, 1863, xxvi., 291.

A mixture of about $\frac{2}{3}$ by measure of raw clay to $\frac{1}{3}$ of burnt clay is suitable for many crucibles. But on purely practical points of this kind, experience alone will enable the operator to decide.

The addition of a highly refractory substance like silica, or of an infusible one such as graphite, or coke, to raw clay may not only tend to counteract the evil due to contraction of the clay, but also fulfil another important purpose. Crucibles composed of good fire-clay may be softened and lose their shape at the high temperatures occasionally produced in furnaces. In such a case, the presence of one or other of the substances above mentioned may act the part of a rigid skeleton to the crucible, and tend to prevent its collapsing in the furnace. According to Berthier, if silica be employed, it may, by long exposure to a high temperature, gradually enter into combination with the clay, and form a more or less homogeneous and pasty mass: and this evil will be specially likely to occur if the particles of silica are too fine.¹ In all mixtures intended for crucibles, it is requisite that there should be a sufficient quantity of raw clay to produce the proper degree of plasticity for working.

It is important to note that the tendency of a crucible to fuse may not be altogether dependent on its *ultimate* composition, but may to a certain extent depend upon the manner in which its *proximate* constituents are mixed. Granite affords a fitting illustration of this fact. This rock consists, as is well known, of an agglomeration of quartz, feldspar, and mica, generally in particles of considerable size, comparatively speaking. Now, when a piece of granite is exposed to a very high temperature in a furnace, even for a considerable time, it will not melt; but if it be previously reduced to powder, and then similarly heated, it will melt with facility.

The selection of a fire-clay for the manufacture of crucibles should be carefully made, especially in the case of those of large size in which a valuable metal is to be melted. Attention should be particularly directed to the presence of iron-pyrites, which in clays from the coal-measures may exist irregularly disseminated in particles. When a crucible made of such clay is heated strongly for any length of time, little cavities, or even perforations, may be produced in the substance of the crucible wherever particles of pyrites have been imbedded. The pyrites is converted into oxide of iron by oxygen derived from the gases of the furnace, which readily permeate most crucibles; and oxide of iron exerts a powerfully fluxing action on clay or silica. That in furnaces filled with ignited fuel such oxidation may occur, I have ascertained experimentally by thus heating crucibles in the substance of which particles of iron-pyrites had been expressly imbedded. When the experiment is made of substituting small pieces of chalk for iron-pyrites, local corrosion also takes place. The presence, however, of a small quantity of lime *uniformly* diffused through a fire-clay may not be injurious, and may possibly tend to render the substance of a crucible made of such clay compact and close

¹ *Traité des Essais*, i. 66.

in grain. The presence of potash or soda in sensible proportion in a fire-clay would certainly make it less refractory ; but in the proportions in which they appear to exist in some of the best fire-clays, their effect may possibly be beneficial rather than otherwise, by soldering the particles firmly together. There is reason to suppose that potash, or soda, is present in all clays ; and no analysis of a fire-clay, in which the proportion of alkali has not been determined, should be considered satisfactory. Potash appears to be present more frequently and in greater quantity than soda ; but the late Mr. Henry informed me that in certain Welsh fire-clays he found from $1\frac{1}{2}$ to 3 per cent. of soda. As all clays appear to be the product of the slow decomposition of feldspar or some other similar mineral containing either potash or soda, the retention of part of the alkali in the residual clay might be expected.

The quality of a fire-clay, with reference to its suitability for crucibles, may be satisfactorily tested on a small scale, either in an air- or small blast-furnace. For this purpose it should be kneaded with water and fashioned into small prismatic pieces with *sharp* edges ; and these when dry should be heated in a covered crucible to a very high temperature. The edges of the pieces should afterwards be examined : if they continue sharp, the clay may be regarded as very refractory ; but if they are much rounded, it is an evidence of incipient fusion ; if the pieces are melted down, the clay is worthless. With a little practice in experiments conducted in this way, very satisfactory results may be obtained. It is necessary to enclose the piece to be tested in a crucible, in order to prevent the corrosive or fluxing effect of the ashes of the fuel. Such trial-pieces as are used in the Metallurgical Laboratory of the Royal School of Mines are represented of the actual size and form in perspective in the annexed woodcut, fig. 5. They are cut out with a knife and then carefully dried. They are placed in the crucible with the large end downwards, in order that the upper portion may be wholly isolated, and not touch the sides of the crucible. Neither the precise form nor the dimensions are material, so long as the edges are sharp.



Fig. 5.
Trial-piece.

The quality of a clay crucible can only be conclusively ascertained by an actual trial under the special conditions to which it is intended to be subjected. To test the property of resisting corrosion, protoxide of lead, or, still better, a mixture of that oxide and red oxide of copper, may be melted in the crucible. If a clay crucible will stand this test for any length of time without being permeated or corroded in a very sensible degree, no other need be applied. Generally, after such a trial of a few minutes only, ordinary crucibles will be very much corroded and even perforated. The substance of the crucible will not be uniformly removed, but will be found to be eaten away irregularly into cavities ; and perforation will, probably, only have taken place in one or two spots. The grain of ordinary clay

crucibles is very irregular, owing to the nature of the mixtures of which they are made; and hence the great irregularity of action of the oxide of lead. It may now be conceived how regularity of structure and fineness of grain should tend to insure uniformity in the corrosive action of the oxide of lead, and so prevent perforation.

It is necessary to distinguish between simple infiltration, and permeation due to corrosion. The body of some crucibles may be so porous as to admit of their being readily infiltrated by liquids which exert no corrosive effect.

As a general rule, clay crucibles will resist permeation and corrosion in proportion to their fineness and regularity of grain; but, unfortunately, in the same proportion is their liability to crack increased. The property of resisting corrosion is not necessarily connected with that of infusibility, but rather the reverse.

Crucibles are used both in the *unburnt* and *burnt* state. Small crucibles are generally kiln-burnt before they are used. The large Stourbridge clay crucibles or "casting-pots," which are extensively employed in the brass-foundries of Birmingham, are never previously burnt. They are gradually and thoroughly dried by the maker in chambers artificially warmed by flues under the floor; and are generally kept by the founder in a dry warm situation on shelves in the casting-shop. In Birmingham, these crucibles are heated in rectangular air-furnaces, about 10 or 12 inches square, and 2 feet deep.² The fuel used is coke. When the furnace is cold, the fire is made, and the bars covered to the depth of a few inches with coke, upon which the crucible is placed *inverted*. The furnace is then filled with coke, and the crucible *gradually* heated to redness. When red-hot, it is taken out of the furnace, and immediately put in again with the mouth upwards. When the furnace is hot, and a fresh pot is needed, the fire must be allowed to go down to a certain extent, or, what is equivalent, a portion of the ignited coke must be removed, and the second pot must be heated with the same precautions as the first, the layer of hot coke at

² The furnaces which Anstey employed (see p. 115) were constructed as follows:—The cavity of the furnace was 11 inches square in superficial area, and was composed of 11 rows of Stourbridge fire-bricks; the wind-hole or flue leading to the chimney was 4 inches square, and placed 3 inches below the top; the bars were either of wrought- or cast-iron, supported on wrought-iron bearers; the depth of the ash-pit below the bars was 10 courses of bricks, and the chimney was rather a high one. "The sides of the furnace," Anstey says, "wear away by heat, so that in the first week the cavity becomes 2 inches wider than at first. It is then brought up to its original width by a lining of glasscutters' mud, which consists of fine sand mixed with particles of glass; and this is renewed twice a week. The cavity of the furnace being only

11 inches across, and 7 inches of that being occupied by the melting-pot, it is of course necessary that the coke used as fuel should be broken into small pieces, not larger than a walnut." Trans. of the Society of Arts, xliii. 34. In 1822 a large silver medal was awarded by the Society of Arts to Mr. Henry Marshall, of Newcastle-on-Tyne, for improved melting-pots for brassfounders and other workers in metals. These pots were made of a mixture of Stourbridge clay, potsherds, and pulverized coke, well incorporated together by beating; and instead of being *thrown* on the potter's wheel, they were fashioned by pressing the mixture, composed as above stated, and duly tempered with water, into a brass mould by means of a core worked by a powerful screw-press. Trans. of the Society of Arts, xli. 52.

the bottom having been previously covered with cold coke. If the pots were put into the furnace at first with the mouth upwards, they would almost certainly crack, notwithstanding every precaution. I have made numerous attempts to use large Stourbridge clay crucibles, after having been kiln-burnt, but I could not succeed in heating them to redness in furnaces in the usual way without cracking; although, for special reasons, I was very desirous of doing so.

It may be stated as a general fact, that the tendency of an earthen crucible to crack increases with its size and thickness; and in the case of crucibles which are used in the kiln-burnt state, that their liability to crack is increased by *over-firing* in the kiln.

STOURBRIDGE CLAY CRUCIBLES.

In 1762 a patent³ was granted to William White for a "new invented manufacture of crucibles for the melting metals and salts," etc. The specification directs that Stourbridge clay and Dorsetshire clay are to be mixed with Woolwich sand and water; and that the mixture is to be trodden with the feet. The use of coke in admixture with Stourbridge clay in the manufacture of crucibles was patented by Anstey: he directed that two parts of fine-ground raw Stourbridge clay should be mixed with one part of the hardest gas-coke, previously pounded, and passed through a sieve of one-eighth of an inch mesh, and that after the addition of the proper quantity of water to the mixture, it should be well trodden; and the precaution is given, not to grind the coke fine, as in that case the pots would be very apt to crack. These pots were reported to last for 14, or even 18, successive fusions of cast-iron, provided they were not allowed to cool in the intervals. They were subjected to severe tests by a committee of the Society of Arts, and stood them in every respect satisfactorily. The Society in consequence awarded to Anstey in the year 1825 a silver medal and the sum of 20 guineas for his invention.⁴

The Stourbridge clay occurs immediately below an inferior sulphurous coal, locally called "Stinking Coal," which varies in thickness from 3 to 5 feet, and lies about 20 yards below the "Thick" or "Ten-Yard Coal." The clay is gotten in a work by itself; the roof is termed "broadcloth," and as it is very much like the clay itself in appearance, it is often mistaken for it. Only a small portion of the clay—about 5 per cent.—is made into crucibles. There are four qualities of clay, namely:—

Best, which is used for crucibles, and sells at about 50 shillings per ton.

Seconds, the small, which is applied to less important purposes.

Black, which is sometimes employed in Sheffield for cast-steel pots, and as an ingredient in plumbago crucibles.

Offal, which is used for fire-bricks, etc., and sells at about 4 shillings per ton of 24 cwt. of 120 lbs. to the cwt.

³ A.D. 1762, Jan. 25 No. 767.

⁴ Trans. of the Society of Arts, xliii. 32.

It is generally found that the clay is better and thicker where the "Thick Coal" is inferior and dislocated, and also where the mines crop out near the river Stour. The clay is worked on the Charter or Butty system, for about 1s. 6d. per ton. The royalties paid (in 1873) are as follow: 16s. per ton for Best; 7s. per ton for Seconds and Black; and 1s. per ton for Offal. As much as 2500l. has been paid per acre to the lessor for the minerals—coal, ironstone, and clay—in this locality.

I have received the following analyses of Stourbridge clay, made in a private laboratory:—

| | Best Clay. | Black Clay. |
|---------------------------|-------------|--------------|
| Silica | 79·25 | 45·29 |
| Alumina..... | 13·57 | 35·27 |
| Sesquioxide of iron | 1·38 | 2·36 |
| Lime | 0·08 | 0·15 |
| Magnesia | 0·42 | 0·08 |
| Alkalies | — | 0·40 |
| Organic matter | — | 1·64 |
| Water | 5·11 | 14·81 |
| | <hr/> 99·81 | <hr/> 100·00 |

It will be perceived that the composition here given differs considerably from that presented in the table of analysis of British fire-clays (p. 98). The "Best Clay," doubtless, contained a notable proportion of free silica, and the "Black Clay" approximates closely in composition to China-clay.⁵

MANUFACTURE OF STOURBRIDGE CLAY CRUCIBLES.—The burnt clay is obtained by pounding and grinding old glass-pots, from the surface of which any adherent glass has been carefully chipped off, only the best Stourbridge clay being used for such pots. The raw clay is ground under edge-stones, which revolve in the usual way on a circular bed, and the ground clay is passed through a sieve. Thus prepared, it is mixed with the right proportion of burnt clay and water, and kneaded by men who tread barefoot upon it until it has acquired the proper degree of consistency. These crucibles are made by hand in the following way:—The workman sits before a bench, in which is a wooden block of the shape of the cavity of the crucible. At the widest end of the block is a flange or projecting border, equal in width to the thickness of the crucible at the mouth measured in its wet state. In the middle of the same end an iron spindle is inserted, which fits into a socket in the bench. The block may thus be made to revolve in the position indicated in the annexed woodcut, fig. 6; it is not fixed, but may be taken out or dropped into the socket at pleasure. On the narrow, or upper end of the block, is placed a lump of tempered clay, which the workman then moulds round the block, by first striking it with a flat piece of wood,

⁵ For the foregoing information concerning the mode of occurrence, etc., of Stourbridge clay, I am indebted to Mr. Samuel Bailey, Mining Engineer, the Fleck, near Walsall, Staffordshire.

and then slapping it with both hands, so as to turn the block more or less each time, as occasion may require. The clay is thus rapidly extended over the whole block down to the flange. A sliding vertical gauge is fixed in the bench near the block, by means of which the thickness of the sides and bottom of the crucible may be regulated. As soon as the moulding is finished, the block is lifted out of its socket and inverted, when the crucible, with a little easing, will gently drop off. The spout for pouring out metal is then fashioned by the finger. The clay may likewise be moulded upon a linen cap wetted, and slipped over the block, so that, on inverting the block, the crucible and cap slide off together, after which the cap may be easily pulled out, especially when the crucible is dry, as it only adheres to the pot while wet. The wet crucible must be very gradually dried. These crucibles are very extensively employed by brass-founders in Birmingham. After they have been once used in the furnace and allowed to become cold, they are worthless. They are largely manufactured by Messrs. King Brothers, Lichfield Street, Birmingham; and I can testify to the excellence of the articles of that firm from an experience of more than 20 years. They make crucibles of twenty-six sizes, the smallest to contain 10 lbs., and the largest 150 lbs., of metal: the former cost 2 shillings, and the latter 12 shillings, the dozen in the "green" or unburnt state; but if burnt, 6 pence and 2 shillings extra on the dozen, respectively. These crucibles are distinguished amongst founders by their prices; thus, the 10 lb. crucibles are commonly called "*2dpy*," and the 150 lb. crucibles "*16d.*," which are abbreviations of twopence-halfpenny and sixteenpence, respectively (1871).

A convenient mould which I have often used for making small Stourbridge clay crucibles is represented in the annexed woodcut, fig. 7, which is a vertical section through the centre. *a* is a vessel of cast-iron, exactly similar in shape to a common flower-pot, open at the top, and perforated at the bottom; *b* is a spindle of wrought-iron, carrying a disc of the same metal on the top; *c* is a flat ring of cast- or wrought-iron, having a lip on the under side, which loosely clips the top of *a*; *d* is a plug of cast-iron, turned in a lathe, which passes through and rests on *c*; *e* is empty space round the depending part of the plug, in which the crucible is to be moulded. The mould is placed on a solid block of wood, in the centre of which is a hole to receive the spindle *b*; the plug is then withdrawn, and a lump of clay, somewhat more than sufficient for one crucible, is put into the vessel *a*, on the top of the disc on *b*; the plug is then driven home by means of a mallet until it comes to the position in which it is shown in the woodcut; the superfluous clay escapes through the ring *c*, around the plug.



Fig. 6.
Crucible block.



Fig. 7.
Crucible mould.
Vertical section
through the centre.

Large crucibles are made by Juleff of a mixture consisting of:—

| | |
|--|--------------------|
| Teignmouth clay* | 1 part by measure. |
| Poole clay | 1 do. do. |
| Sand from St. Agnes' Beacon, Cornwall..... | 2 do. do. |

The composition of these clays will be found in the table, p. 99.

When smaller and less refractory crucibles are needed, the same mixture is employed, with the addition of an eighth-part of China-clay from St. Austell. I am indebted to Mr. Juleff for this information. In these crucibles we have an illustration of the use of silica in admixture with clay.

LONDON CRUCIBLES.

These crucibles have a reddish-brown colour, and are close in grain. We find them very liable to crack, so that they require special precautions in their management; and they will not stand reheating. In reference to assay-crucibles of this kind manufactured by Ruel, of High Holborn, the late Mr. Henry reported to the Jury of the Great Exhibition in London, 1851, that "they resist the action of fused oxide of lead much better than any he had tried."⁷ This accords with the experience obtained in our metallurgical laboratory. One of Ruel's crucibles above referred to is shown in section in fig. 9.



Fig. 9. Section of London crucible, to the scale of $\frac{1}{4}$.

WHITE FLUXING-POTS.

In recent years we have had good earthen crucibles from the Patent Plumbago Crucible Company, Battersea Works, belonging to Messrs. Morgan Brothers. They are well moulded and very refractory; they have a smooth surface, and withstand the action of fluxes satisfactorily. They resemble crucibles of the best French make in appearance, and are designated by the name of *white fluxing-pots*. The material of which they are made is a highly refractory French fire-clay, from the vicinity of Rouen; and formerly French workmen were employed by Messrs. Morgan. Excepting the very small crucibles, we find that they are liable to crack when exposed to sudden changes of temperature; and that towards the bottom they are apt to become fissured within, though not sufficiently so to allow the contents to escape. In this respect they are inferior to similar crucibles of French manufacture; a circumstance which may, probably, be due to their too great

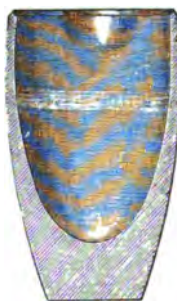


Fig. 10. Section of white fluxing-pot, to the scale of $\frac{1}{4}$.

* This clay is got at Bovey-Tracey, in Devonshire, from the Lignite beds which occur there, and, as previously stated, de-
rives its name from being shipped at the port of Teignmouth.
⁷ Jury Reports, p. 585.

thickness. After having been once used and allowed to become cold, they are very liable to crack on being reheated. The term *white fluxing-pot* is given to these crucibles in order to distinguish them from the well-known variety of crucibles called *London crucibles*, the name of London serving to indicate *the kind of crucible*, rather than *the place of manufacture*. The smallest are $2\frac{1}{2}$ inches and the largest are $8\frac{1}{2}$ inches high. Fig. 10 represents the section of one of medium size.

HESSIAN CRUCIBLES.

These crucibles have long had a high reputation, and formerly were those most frequently employed in chemical laboratories. They are generally triangular in shape at the top, so that substances melted in them may be conveniently poured out from each corner. They are usually sold in "nests" of six crucibles, which gradually diminish in size, so as successively to fit into each other. Crucibles which I have purchased as Hessian in England, and tried during many years, have not justified the high reputation for refractory quality to which the genuine and properly made Hessian crucible is entitled. They are readily permeated by molten oxide of lead. In the character of their body, and in composition and qualities, they closely resemble Cornish crucibles. They are made of a mixture of equal weights of Almerode clay and sand.⁸ According to the analysis of Berthier, the Hessian crucible is composed of:—

COMPOSITION OF HESSIAN CRUCIBLES.

| | |
|--------------------------|------------|
| Silica..... | 70·9 |
| Alumina | 24·8 |
| Sesquioxide of iron..... | 3·8 |
| | <hr/> 99·5 |

Wurzer appears to have analysed several Hessian crucibles, as he has stated the amount of variation in the proportion of each ingredient.⁹ He has also analysed the Almerode clay, which he found to be composed as follows:—

COMPOSITION OF ALMERODE CLAY.

| | |
|-------------------------|-------------|
| Silica..... | 10·1 |
| Alumina | 65·4 |
| Oxide of iron | 1·2 |
| Carbonate of lime | 0·3 |
| Water | 23·0 |
| | <hr/> 100·0 |

This result is so entirely opposed to that of Berthier, who analysed the same clay, and to all other analyses of fire-clays, that Wurzer's results are, doubtless, erroneous. However, he mentions the presence of titanio acid, which, as already stated, may, according to the recent

⁸ Lehrbuch der chemischen Technologie, Dr. F. Knapp, 1847, i. 598.

⁹ Kerl, Handbuch der metallurgischen Hüttenkunde, i. 136.

investigation of Riley, be detected in all fire-clays.¹ The presence of titanic acid to the extent of 1 per cent. in the clay of Gross-Almerode and in a clay from another locality was announced in 1853.² But so long ago as 1835 a paper was published on the presence of this acid in Hessian crucibles by Brett and Bird,³ who made four analyses, in which the minimum of titanic acid was 3·5 per cent., and the maximum 21·0 per cent. But their method of analysis is not satisfactory. In consequence of this paper, the presence of titanic acid was sought for in the substance of Hessian crucibles by Schwarzenberg in Wöhler's laboratory, but none was detected. Wöhler concluded, therefore, that Brett and Bird had mistaken silica or alumina, or both, for titanic acid.⁴

FRENCH CRUCIBLES.

Berthier speaks highly of the "creusets de Paris," manufactured by Beaufay. He states that, compared with Hessian, they are quite as refractory, equally resist sudden alterations of temperature, and retain molten litharge much longer. They are made of about one part by weight of clay from Andennes and two parts of the same clay burnt and coarsely pounded. They are fine in body. In order that their surface may be very even, they should before using receive a thin coating, both inside and outside, of pure clay. A piece of these crucibles heated to 150° p. became a little rounded upon the angles and edges, but without losing its form, and acquired the smooth, shining fracture of stone-ware: its surface became copper-red.⁵ Water easily exudes from them. The crucibles termed "creusets de Saveignies," which are manufactured near Beauvais by Deyeux, are thus described by Berthier. They are well-moulded, thin, of uniform thickness throughout, very even, fine and homogeneous in grain, porous, retain water, but not sufficiently to prevent the outer surface from becoming moist, and they resist sudden alternations of heat and cold without breaking. They are more refractory than those of Beaufay; for when a piece is heated to 150° p., it retains its granular texture and does not present the fracture of stone-ware, although it becomes somewhat rounded on the angles, and acquires a copper-red colour on the surface. Nevertheless, the crucibles of Deyeux are much inferior to those of Beaufay, as they will only retain molten litharge during a very short time. They are made of a mixture of clay and quartz in fine powder. Deyeux and others exhibited collections of crucibles at the Great Exhibition in 1851. In the Report⁶ of the Jury, which was drawn up by Dufrénoy, it is stated that "the crucibles manufactured by Deyeux are of two distinct kinds, according to the uses for which they are destined: those intended for fusing bronze, copper, gold, and silver, are marked with the letters 'A. D.';

¹ Riley on Titanic Acid. *Quart. Journ. of the Chem. Soc.*, 1862, xv. 311.

² Kennigott, Uebersicht der Resultate mineralogischer Forschungen, for 1854, p. 161. Published 1856.

³ *Phil. Mag.* vi. 113.

⁴ *Ann. der Phys. und Chem.* 1835, xxxv. 527.

⁵ *Traité des Essais*, i. 168.

⁶ P. 27.

the others, manufactured expressly for the fusion of cast-iron or steel, are marked 'No. 28.' These crucibles, it is further stated in the Report, were introduced about ten years previously; and yet Berthier has described and given an analysis of them in his '*Traité des Essais*,'⁷ published in 1834. The exhibitors presented favourable testimonials as to their quality from Thénard, D'Arcet, and Despretz. The following analyses of the crucibles of Beaufay and Deyeux are by Berthier.

COMPOSITION OF BEAUFAY'S AND DEYEUX'S CRUCIBLES.

| | Beaufay's. | Deyeux's. |
|--------------------------|-------------|------------|
| Silica..... | 64.6 | 72.3 |
| Alumina | 34.4 .. | 19.5 |
| Sesquioxide of iron..... | 1.0 | 3.9 |
| Water | — | 1.8 |
| | <hr/> 100.0 | <hr/> 97.5 |

Some of Deyeux's crucibles, which we have tried, are perfection in shape and excellence of manufacture.

BELGIAN CRUCIBLES.

Henri Sainte-Claire Deville informed me in 1856 that all the varieties of crucibles at the Great Exhibition in Paris, 1855, were tested, and that those of Coste (*fabricant de creusets réfractaires à Tilleur, près Liège, Belgique*) were found to be by far the best.

We have made trial of Coste's small crucibles, with which we were supplied by Mr. George Matthey, of Hatton Garden, and found no difficulty in melting them, so that they must have been very inferior to those previously examined by Deville; and, subsequently, in May 1862, Deville admitted to me that he had been mistaken as to the quality of Coste's crucibles.

CARBONACEOUS CRUCIBLES.

GRAPHITE, BLACK-LEAD, OR PLUMBAGO CRUCIBLES.

As graphite is not of itself plastic, it is mixed with refractory clay in sufficient proportion to produce a material capable of being moulded into crucibles on the potter's wheel or otherwise. Intermixture of the ingredients is best effected by a pug-mill, treading by the feet being, I am informed, unsatisfactory.

Good black-lead crucibles may be characterized by the following properties: they support, even when of the largest size, the greatest and most sudden alterations of temperature without cracking; they may be used after having been repeatedly heated and cooled, so long as they are not too much reduced in thickness by the burning away of the graphite to bear the weight of the metal, which may be melted in them, and to admit of being held by tongs without breaking; their surface within should be smooth, so that particles of melted metal may not hang about the sides. Black-lead crucibles have, however, the disadvantage of being expensive. Although the graphite on the

outer surface of a crucible will, in the course of time, burn away, yet it is to a certain extent protected by the intermixed clay from the action of any free oxygen existing in the gases of the furnace, the clay left exposed by the combustion of the graphite in the extreme outside layer of the substance of the crucible becoming more or less vitrified by the action of the ashes of the fuel, and so forming a coating which tends to prevent the oxidation of the graphite in the underlying substance of the crucible. Nevertheless, when these crucibles are long exposed to a very high temperature, much of the graphite will burn away; and with a view to lessen this evil, their outer surface, previously to use, is sometimes coated with clay, by dipping them into a mixture, of the consistency of cream, prepared by kneading clay with water containing borax in solution.

Many years ago I had occasion to employ black-lead crucibles of large size, capable of holding from 40 to 60 lbs. of metal, and to subject them during many hours consecutively to the highest temperature of air-furnaces, in which nickel could be easily melted by pounds at a time. I found that while some stood well under these conditions, though not coated externally with clay, others were worthless. This difference must be due either to the quantity or quality, or both, of the matter naturally occurring in, or artificially mixed with, the graphite, or, as previously stated, to the state of aggregation of the graphitic carbon itself. When a black-lead crucible becomes soft and yielding under the pressure of tongs at high temperatures, it is generally owing to a deficiency in the refractory quality of the intermixed clay; for graphitic carbon, it will be remembered, neither fuses nor even softens at the highest temperatures attainable in furnaces.

It should be remembered that native graphite frequently contains a sensible amount of oxide of iron, which may be reduced to the metallic state by heat, so that matters melted or heated in such crucibles may become contaminated with iron: and sometimes it is intermixed with iron-pyrites.

ENGLISH BLACK-LEAD CRUCIBLES.

We have found the black-lead crucibles manufactured by Ruel, of High Holborn, to be of excellent quality, and capable of resisting the highest temperature of our air-furnaces, in which we can melt manganese or wrought-iron with facility. I used them with perfect success in numerous experiments on the artificial formation of silicates, which, in many cases, require a very high and long-continued heat. The black-lead crucibles which Ruel placed in the Great Exhibition of 1851 were reported on very favourably by T. H. Henry, who subjected them to severe tests. "Mr. Ruel," writes Henry, "has so improved the black-lead or plumbago crucibles as to drive the foreigner out of the English market. I have repeatedly tried them, and found them excellent. Messrs. Brown and Wingrove, the gold-melters, use them exclusively."⁸ That firm

⁸ Jury Report, p. 585.

furnished the Jury with the following written opinion of their experience of these crucibles:—They are “the best quality for all the most important purposes for which such utensils are required.” One of Ruel’s black-lead crucibles, marked “Ruel’s Improved No. 5,” yielded by incineration 64·00 % of red-coloured residue.



Fig. 11.
Section of one of Juleff’s black-lead crucibles, to the scale of $\frac{1}{4}$.

Black-lead crucibles for the use of tin-assayers are manufactured by Juleff, of Redruth, Cornwall. Their internal surface is very smooth. Annexed is a woodcut, fig. 11, showing one of these crucibles in section. The substance of the crucible from which fig. 11 was drawn, in 1861, yielded by incineration 37·10 % of dark red-coloured residue; and that of another of Juleff’s crucibles supplied to the Metallurgical Laboratory of the Royal School of Mines, in 1873, yielded 39·15 % of dark red-coloured residue, thus showing that the proportions of graphite and clay in these crucibles have remained substantially the same from 1861 to the present time.

The manufacture of black-lead crucibles is carried on on a large scale by Messrs. Morgan Brothers at Battersea, near London, where they have erected extensive and well-arranged works. We have used their small black-lead crucibles at the Royal School of Mines for many years, and have found them excellent; but we are unable to report from personal experience concerning those of large size, for which, we are informed, there is a great demand both in this country and abroad.

I have had the pleasure of visiting these extensive works in 1865, and again in 1871, and of seeing the process of manufacture. The plumbago is hand-picked, ground, and passed through sieves; the powder, thus prepared, is mixed with a due proportion of fine fire-clay, and kneaded with water to the proper consistency. Intermixed oxide of iron is dissolved out of the plumbago by digestion with dilute sulphuric acid in leaden tanks, and subsequent washing with water. The crucibles are either raised by hand on a potter’s wheel, or made by machinery, carefully dried, and then burnt in saggars.

MANUFACTURE OF BLACK-LEAD CRUCIBLES BY MACHINERY.

Messrs. Morgan have obtained a patent¹ for the manufacture of these crucibles by machinery of which the following is a description.²

a, the forming tool, made of cast-iron; it is curved outwardly according to the shape intended to be given to the crucible.

b, a cast-iron block, into which the root of *a* is fitted.

c, a cast-iron frame, which *b* traverses longitudinally.

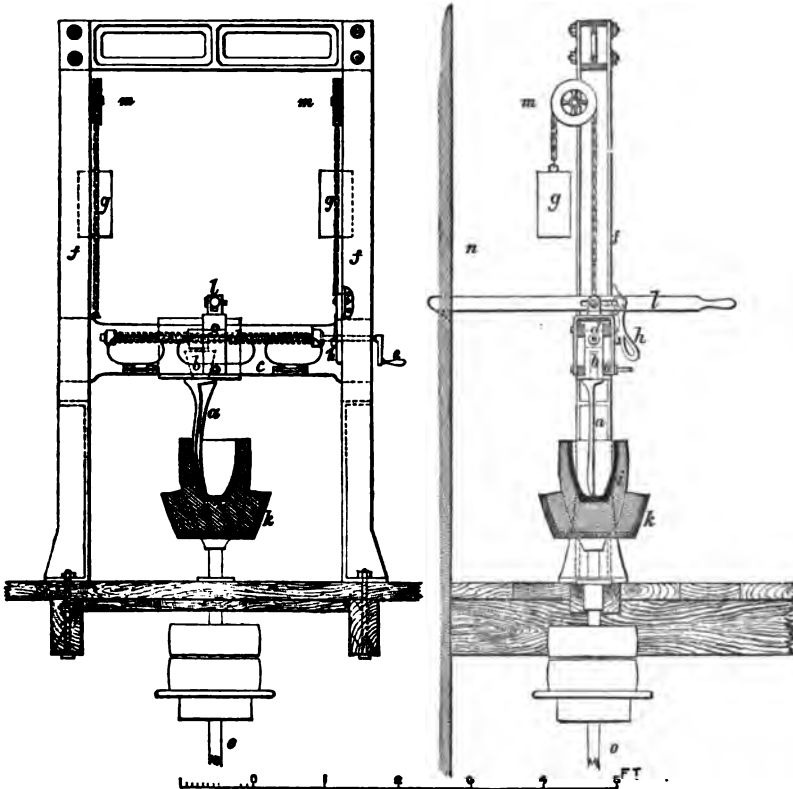
d, a screw spindle, which moves *b* to and fro.

¹ Improvements in Apparatus for the Manufacture of Crucibles and other Hollow Articles from Plastic Materials, A.D. 1866, No. 3292.

² I have much pleasure in acknowledg-

ing my obligation to this enterprising firm, for freely permitting inspection of their machinery, and communicating practical information concerning the process, with a view to publication in this volume.

- e*, the handle of *d*.
f f, cast-iron standards, which act as guides to *c*.
g g, counterbalance weights, enabling *c* to be raised or lowered with facility.
h, a catch to hold *c* in position.
i, the crucible mould, made of plaster of Paris.



Machine used by Morgan Brothers for making crucibles; drawn by Mr. W. Prim.

Fig. 12. Front elevation; showing the mould in vertical section through the centre.

Fig. 13. Side elevation; showing the mould in vertical section through the centre.

k, a cast-iron bucket, in which *i* is placed. (If *i* does not fit *k*, the intermediate space is filled with any convenient packing, plaster of Paris, or other suitable material, as shown in the woodcuts.)

l, a lever for depressing *c*.

m m, pulleys, over which chains pass, connecting *c* with *g g*.

n, a back wall or standard, which acts as a fulcrum for *l*.

o, a vertical spindle, which gives rotation to *i*.

To form a crucible, a lump of the material in a soft plastic state is put into the mould, which is set rotating; the tool is then depressed, and by means of the screw is gradually moved to the left as shown in fig. 12, whereby the material is spread over the interior

of the mould to the desired thickness; any excess of material escapes over the edge of the mould. The tool is then raised, the rotation of the mould is stopped, a lip fashioned by hand, and the mould with the crucible in it set aside to dry. In drying the crucible contracts and so separates from the mould; it is then turned out and fired in a saggar in a suitable kiln.

COMPOSITION OF ENGLISH BLACK-LEAD CRUCIBLES.

| | I. | II. | III. |
|---------------------|---------------|---------------|---------------|
| Silica | 51.40 | 45.10 | 50.00 |
| Alumina | 22.00 | 16.65 | 20.00 |
| Oxide of iron | 3.50 | 0.95 | 1.50 |
| Graphite | 20.00 | 34.50 | 25.50 |
| Lime | 0.20 | 0.00 | 0.50 |
| Water | 1.80 | 2.50 | 3.00 |
| Loss | 1.10 | 0.30 | 0.50 |
| | <u>100.00</u> | <u>100.00</u> | <u>101.00</u> |

I. II. III. The analyses were made by M. Ch. Mène, and the crucibles are stated to have been of very superior quality, but the name of the manufacturer is not given.³

The substance of a 70-lb. black-lead crucible made by Messrs. Morgan for melting brass has been examined in the Metallurgical Laboratory of the Royal School of Mines, and found to yield by incineration, in a muffle heated nearly to whiteness, 51.66% of residue, so that the graphite, estimated by loss, amounted to 48.34%. Two incinerations were made, each with 25 grains of material, and the residues, which had a yellowish-white or cream colour, weighed 12.92 grains and 12.91 grains respectively.

FOREIGN BLACK-LEAD CRUCIBLES.

Of the black-lead crucibles manufactured on the Continent, those of Passau have long been known. At the Great Exhibition of 1851 the firm of Lorenz, Kapeller, and Son, of Hafnerzell, near Passau, exhibited a series of these crucibles, which were reported to be highly refractory; they were well made, and one was unusually large, being 2 feet high and 20 inches wide at the mouth. Passau crucibles are said to be made of a mixture of 1 part of clay from Schildorf and 2 or 3 parts of an impure graphite which occurs in gneiss in that locality.⁴

Good black-lead crucibles were shown in the London International Exhibition of 1862 by Messrs. Gruber and Raum, of Nuremberg, the manufacturers. I tried two of these crucibles, one of which was of large size, in the Metallurgical Laboratory of the Royal School of Mines, in the presence of Dr. H. Wedding, of Berlin, and M. Dubocq, members, like myself, of the Jury of Class I. The smaller one was put mouth upwards into a *hot* furnace heated with coke, when pieces split off round the bottom on the outside. Clay evidently

³ Comptes rendus, 1867, lxiv. 1093.

⁴ Knapp, Lehrb. der chem. Technol. 1847, p. 598.

entered largely into their composition. Although they did not stand the test of sudden heating in a satisfactory manner, yet they were accompanied by an official notice from the authorities of the Berlin Mint to the following effect:—Two black-lead melting-pots were supplied by Gruber and Raum, each capable of holding 400 kilogrammes of silver alloy containing 90% of silver, the alloy of which Prussian thalers are made; after having been sufficiently heated, they were used for melting such an alloy in furnaces of proportionate size with charcoal for fuel; one of the pots stood 55 and the other 59 pourings, though the process was interrupted twice.

The firm of J. P. Goebel and Son, Gross-Almerode, near Hessen-Cassel, also sent black-lead crucibles to the same Exhibition. In their price-list 18 sizes were specified, of which the smallest and largest were capable of holding 1 and 600 kilogrammes of molten metal respectively, the price of the former being 1·8 penny and that of the latter £4 10s. It was announced that they might be used in the melting of silver and brass from 40 to 50 times, of copper and German silver from 20 to 30 times, and of cast-steel from 6 to 7 times.

CARBON CRUCIBLES.

The carbon crucibles which Deville employs in the furnace, which bears his name and is described at p. 143 in the sequel, are turned in a lathe out of gas-retort carbon. They should be perfectly cylindrical, and never exceed the height of 4 inches, inclusive of the thickness of the bottom, whatever may be their width. The reason assigned for this is, that the zone of maximum temperature in Deville's furnace hardly extends to the height of $3\frac{1}{4}$ inches. These crucibles may be freed, at least to a certain depth below the surface, from impurities, such as sulphur, iron, silica, and alumina, by heating them, along with their covers, in earthen crucibles, through the bottom of which a current of chlorine is introduced. The carbon often loses sensibly in weight by this process, but keeps its solidity. When used, a carbon crucible is placed in another crucible of lime or refractory clay, and the space between the two is filled with powder of alumina, which has been previously exposed to a white-heat. A cover of gas-retort carbon is placed on the carbon crucible; over this, powder of alumina is spread and pressed strongly down, and upon the top is placed a clay cover. During the process of heating, the outer crucible may melt completely, yet the carbon crucible within will remain protected by the alumina, which the clinker of the fuel will scarcely attack. It is hardly necessary to state that the fusion of the outer crucible of lime could only be caused by the action of the ashes of the fuel.

Carbon crucibles may be made from a mixture of tarry matter and the powder of anthracite, charcoal, coke, gas-retort carbon, or other material which may properly be designated carbon. Observations on the manufacture and mode of using such crucibles will be found in the sequel at p. 140, under the head of Lining Crucibles with Carbon. It is now more than twenty years ago since I successfully

employed large crucibles made of a mixture of ground gas-retort carbon and tar in the manufacture of alloys of manganese and copper.

CRUCIBLES COMPOSED OF STOURBRIDGE CLAY, COKE,
AND PLUMBAGO.

A reward of £20 was given to Mr. Charles Sidney Smith by the Society of Arts in 1828, for the manufacture of crucibles composed of the ingredients above mentioned. The process is thus described:—A convenient quantity of Stourbridge clay is to be put on a sieve of one-fourth of an inch mesh, and carefully hand-picked, all pebbles and other impurities being thrown aside; it is then sifted on a board and put into a bin. Those pieces which will not pass through are pounded in a mortar with a spring-pestle till they are fine enough to pass through a sieve of one-eighth of an inch mesh, and this fine clay is put into a barrel by itself. The coke is oven-burnt and not gas-coke, which is said to be of inferior quality; the tops and bottoms are knocked off, and only the middle part, which is of a uniform firm texture, is reserved for use. The coke is to be pounded in a mortar, taking care so to moderate the blow of the pestle as to produce as little dust as possible, thrown on the fine or last-mentioned sieve, and all that passes through is to be rejected; it is then to be transferred to the coarser sieve, and what comes through is of a proper size. The plumbago, which was Mexican, is to be reduced to very fine powder. The board called the *walking* board, on which the ingredients are mixed and tempered, is 6 feet square, having cross-pieces on the underside to raise it about an inch from the ground. The process commences by mixing on the coarser sieve eight quarts of clay and five quarts of coke previously treated as above described, and sifting them together on the walking board; the mass is further to be mixed by hand until it appears to be uniform, when it is to be collected in a heap. *Clean* water is now to be stirred in until the mass acquires the consistency of mortar. One treader is then to tread the mass well on the board with his bare feet, working it chiefly with the heels: when trodden, it is to be turned over or thrown with a spade, and is again to be trodden, alternating these two operations for about twenty minutes. A mixture is to be made on the fine sieve of four quarts of finely pounded clay and two pounds of the pounded plumbago, and a little of it is to be sifted over the mass on the board, when the whole is to be trodden and thrown in the manner above described; and so the process is continued until the ingredients are thoroughly incorporated and the air has been all trodden out. The mixture thus prepared should remain for a night in lump, and the manufacture of the melting-pots proceeded with on the following morning. The pots are fashioned on a block or core, such as is described at p. 116. The cap of the core should be of basil or thin sheepskin. Everything being ready, the core is first to be rubbed well with plumbago, to prevent the cap from sticking to it; the cap is then to be put on the core and a piece of the mixture, or *walk*, as it

is technically called, large enough for the melting-pot, is to be cut off. A pot capable of holding 70 lbs. of cast-iron requires $16\frac{1}{2}$ lbs.; and one for 35 lbs. of brass requires 10 lbs. The piece is to be worked and beaten up well on the walk-board, and carefully gathered into a lump, which, after a hollow has been made in it, is to be fixed on the top of the core. The workman then strikes it with what is called a *flatter*, which is a flat piece of board 4 inches square with a handle beginning at the top and bringing down the clay gradually till it has got as low as the rim at the bottom of the core. During this time, the spindle of the core being grasped by one hand and turned gently round, the core itself, with the clay on it, is brought successively under the action of the flatter. Great care is to be taken during this operation that no air gets into it, or, if any bubble should appear in the clay, it is to be cut out with a knife. The bottom of the pot is now to be beaten quite flat, making it of the proper thickness by the gauge (see p. 117, *antea*), and observing that the core is not made to rise from its socket by any clay getting under the bottom of the core; for the consequence of this would be that the bottom of the pot, though regulated by the gauge, would be too thin to the extent of the rising of the core. The workman now dips one hand in water, and presses the pot, rubbing it from top to bottom, while the other hand is turning round the core. The effect of this is that the pot acquires uniform thickness, not varying in any part so much as $\frac{1}{16}$ of an inch. Finally, to complete the process, the pot is to be smoothed all round as well as at the bottom. The first pot of each day's work should be cut up with a knife, to ascertain that there are no air-holes in its substance, and that the tempering has been properly performed. As a soft, new-made pot might get out of shape by being handled, the core, with the pot on it, is carried to a quiet sheltered place, and the pot being set on its bottom, the core is raised out, leaving the cap within, which itself parts from the pot with a little management. The lip is then made by pressing the handle of a trowel from within against the edge of the pot, having placed the fore-finger and thumb, one on each side of the edge, to limit the action of the pressure. It is by no means an unnecessary precaution to put the new-made pot in a quiet place; for if it is subjected to any considerable jarring before it gets dry and hard, it will sink and not carry its rated charge of metal. From twenty to thirty-six melting-pots of excellent quality may thus be made in a day.⁵

ALUMINA, LIME, AND MAGNESIA CRUCIBLES.

ALUMINA CRUCIBLES.

Alumina is extremely refractory and cannot be melted, even at the highest temperatures attainable in furnaces, though, according to Gaudin, it may be fused into glass-like beads in the flame of a spirit-

⁵ Trans. of the Society of Arts, xlvii. 54 *et seq.*

lamp supplied with a jet of oxygen. If a material should be required, either for crucibles or furnaces, which is entirely free from silica, is very refractory, and is sufficiently plastic for moulding, alumina might reasonably be supposed to be suitable. But owing to the great shrinking which hydrated alumina undergoes by drying and firing, it cannot be used alone for crucibles.

It should be borne in mind that alumina may act as a base as well as an acid. In clay it is basic, being combined with silica; while in spinel it is acid, as is expressed by the formula of that mineral, $\text{MgO}, \text{Al}_2\text{O}_3$ [idem].

Alumina crucibles, according to Deville,¹ may be made of a mixture of gelatinous alumina and a proper proportion of alumina which has been previously heated very strongly during a long time. He prefers alumina prepared at a very low temperature from ammoniacal alum, as it forms a plastic mixture with water; and it is very difficult to triturate the lumps in ordinary gelatinous alumina. Instead of calcined pure alumina, Deville also uses the fine powder of the product obtained by exposing an intimate mixture of equal parts by weight of alumina and pounded marble to the highest temperature of a good air-furnace. It is often scoriaceous and translucent, and resembles dried flour-paste; it occasionally contains little *geodes* full of crystals; and it may be properly designated aluminates of lime. It is recommended as an excellent ingredient for crucibles not intended to be exposed to the highest temperatures, because it imparts to their substance, when fired, a degree of hardness much exceeding that of porcelain, and even renders it slightly translucent. With equal parts of plastic alumina, calcined alumina, and the product last described, crucibles may be prepared which soften a little at the melting-point of platinum, but which, by being strongly heated, acquire a remarkable degree of solidity. For very high temperatures less aluminate of lime should be added; but it is always desirable that the mixture should contain from 5 to 10 per cent. of lime. Deville remarks that, however these crucibles may be made, when once fired, they will stand every test. They resist sudden and great changes of temperature, and almost every kind of matter, even sodium, may be heated in them.

BAUXITE AS A SUBSTITUTE FOR ALUMINA.

It has been recommended to use the mineral named bauxite or beauxite in the manufacture of crucibles, from its containing a large proportion of alumina.² Berthier was the first to analyse this mineral, and publish an account of it, so long ago as 1821.³ The specimen upon which he operated came from the vicinity of Arles in the south of France, where it occurs as a superficial deposit on a hill, called

¹ Ann. de Chim. et de Phys. s. 3, 1856, xlv. 195.

² Wagner's Jahresbericht, 1869, p. 359.

³ Ann. des Mines, 1821, vi. 531. See also Dana's System of Mineralogy, 1868, p.

174; H. Sainte-Claire Deville's Memoir, Ann. de Chim. et de Phys. s. 3, 1861, lxi. 309 *et seq.*; Kennigott, Uebersicht der Resultate mineralogischer Forschungen, 1868, p. 119.

"Colline des Beaux." It was regarded as an alluvial iron-ore. It is abundant in the departments of the Gar and Var, in the South of France, in Calabria, in the Grecian Archipelago, and in Senegal; and other localities might also be mentioned. A mineral is found in Styria, between Feistritz and Lake Wochein, which has received the name of wocheinite, but is considered to be identical with bauxite. Bauxite occurs in round concretionary disseminated grains, massive, oölitic, earthy, and clay-like; it varies much in colour, being whitish, greyish, ochre-yellow, brown, or red (Dana). The varieties of it richest in alumina are used as the source of aluminium by the producers of that metal, and are accordingly designated aluminium-ore. Deville has examined bauxite from various localities, and found it to contain the following ingredients:—

| | |
|------------------------------------|-------------------------------------|
| Silica. | Carbonate of lime. |
| Titanium (? titanic acid). | Phosphoric acid. |
| Alumina { Crystallized (corundum). | Vanadic acid, in minute proportion. |
| Amorphous. | Water. |
| Sesquioxide of iron. | |

It is transformed at a very high temperature into crystalline corundum, comparable to emery in appearance as well as in physical and chemical properties. It dissolves slowly in hydrochloric acid, with the exception of a residue of silica, titanic acid, and a little corundum. In order that this solution should be complete, it ought to be made in a stoppered bottle, kept hot, and shaken at intervals. The residue is red, rose-coloured, passes through filters like titanic acid, and retains a little vanadium. The concentrated solution when evaporated yields crystals of impure chloride of aluminium of the greatest beauty (Deville).

COMPOSITION OF BAUXITE FROM VARIOUS LOCALITIES.

| | I. | II. | III. | IV. | V. | VI. | VII. |
|------------------------|--------|-------|-------|-------|--------|--------|-------|
| Alumina | 58.1 | 57.6 | 55.4 | 30.3† | 33.2 | 64.24‡ | 40.0 |
| Sesquioxide of iron... | 3.0 | 25.3* | 24.8* | 34.9* | 48.8* | 2.40 | 33.6 |
| Silica | 21.7 | 2.8 | 4.8 | — | 2.0 | 6.29 | 2.0 |
| Titanic acid..... | 3.2 | 3.1 | 3.2 | — | 1.6 | — | — |
| Lime..... | — | — | — | — | — | 0.85 | — |
| Carbonate of lime..... | traces | 0.4 | 0.2 | 12.7 | (5.8§) | — | — |
| Magnesia..... | — | — | — | — | — | 0.38 | — |
| Sulphuric acid | — | — | — | — | — | 0.20 | — |
| Phosphoric acid | — | — | — | — | — | 0.46 | — |
| Water | 14.0* | 10.8 | 11.6 | 22.1 | 8.6 | 25.74 | 24.7 |
| | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.56 | 100.8 |

* By difference.

† With silica and titanium.

‡ With a very small quantity of titanic acid.

§ Corundum; the limestone having been removed by weak hydrochloric acid (*sic*)Analyses I. to V., inclusive, by Deville.⁴

I. It is typical of the most siliceous kinds, is not plastic, and con-

⁴ Ann. de Chim. et de Phys. s. 3, 1861, lxi. 321. The method of analysis is described with much detail, and should be consulted by the analytical chemist.

sists of two distinct strata; one white, which was analysed, and the other red and richer in iron. From the "Communal des Baux," environs of Arles.

II. Compact, deep-red, nearly brown, considered as an iron-ore. From Revest, environs of Toulon.

III. Compact, composed of round grains of bauxite imbedded in the same substance agglutinated. This is the commonest form of the mineral. It is almost always pisolitic, and the grains are cemented occasionally with rhomboidal crystallized carbonate of lime. From Allauch (Var).

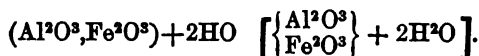
IV. An ore with a calcareous body (*à pâte calcaire*) was the subject of this analysis. It is very hard, very compact, and constitutes almost entire hills in the "Commune des Baux" (above described as the "Communal des Baux").

V. From Calabria, where it occurs in considerable masses, which in respect of abundance may be compared with the commonest rocks.

VI. Analysis by Lill. It occurs between Feistritz and Lake Wochein, in Styria, in a deposit 12 feet thick, which forms the junction of the Triassic and Jurassic formations, and of which part is red, owing to the presence of oxide of iron. It contained traces of manganese, potassium, sodium, and lithium.⁵ Other analyses of it have been made by Schnitzer, which confirm the accuracy of that in the table.⁶ The varieties richest in alumina are such as are light-coloured, and vary in tint from yellowish-white to brown-yellow. The dark-brown sorts are richest in iron and most frequent.

VII. Analysis by Berthier. From Upper Senegal. It is reported that the mineral contained a trace of chromium, but not of manganese, and that it was smelted as iron-ore by the negroes.⁷

The formula which has been deduced for bauxite is:—



Taking the ratio between the equivalents of alumina and sesquioxide of iron as 3 : 1, the calculated composition per cent. is as follows (Dana):—

COMPOSITION OF BAUXITE PER CENT., CALCULATED FROM THE PRECEDING FORMULA.

| | |
|--------------------------|-------------|
| Alumina | 50.4 |
| Sesquioxide of iron..... | 26.1 |
| Water | 23.5 |
| | <hr/> 100.0 |

At present the formula of bauxite cannot be regarded as established. All that can be asserted is, that it is a hydrate of alumina, and its formula must, as Kennigott suggests, be left indefinite, thus—



⁵ Dana's System of Mineralogy, 1868, p. 147.

⁶ Wagner's Jahresbericht, 1867, p. 267.

⁷ Ann. des Mines, 1820, v. 129.

The so-called aluminous ore from Belfast is evidently bauxite, as will appear from the following analyses of it which I published in the volume on Iron and Steel in 1864 (p. 207, Nos. 9A and 9B in Table III.).

COMPOSITION OF ALUMINOUS ORE FROM BELFAST.

| | I. | II. |
|------------------------------|--------------------------------------|--------|
| Alumina..... | 27.95 | 34.57 |
| Sesquioxide of iron | 35.91 | 27.93 |
| Protoxide of iron | 6.57 | 5.08 |
| Protoxide of manganese | 0.05 | traces |
| Lime | 0.60 | 0.91 |
| Magnesia | 0.20 | 0.62 |
| Potash | 0.49 | — |
| Silica | 9.75 | 9.87 |
| Titanic acid | } Present, but not estimated } | } 3.51 |
| Phosphoric acid | | |
| Water | 18.60 | 19.36 |
| | 100.12 | 101.85 |

I. Analysis by C. Tookey in my laboratory. The ore was a conglomerate, composed of small rounded pea-like pebbles cemented together. II. Analysis by E. Riley.

A very refractory substance, regarded as red clay, occurs at Cape de Gata, Bay of Almeria, Andalusia, in the South of Spain. It is suggested that it would be an excellent material for furnaces in which the highest temperatures are required. But the following analyses of it by Terreil will show that it should rather be regarded as bauxite, or as a nearly allied mineral.* The specimens operated upon were taken from an old working, where, according to local tradition, the Moors procured it for the manufacture of their terra-cotta ornaments on the ancient monuments of Spain.

COMPOSITION OF SPANISH CLAY.

| | I. COMMON RED CLAY. | II. VERY FINE RED CLAY. |
|----------------------------------|---------------------------|-------------------------------|
| Silica | 26.84 | 15.17 |
| Alumina..... | 35.42 | 48.26 |
| Sesquioxide of iron | 9.81 | 7.67 |
| Vanadium | traces | traces |
| Potash as silicate | traces | traces |
| Chloride of potassium | 1.62 | 0.82 |
| Chloride of sodium | traces | traces |
| Lime and magnesia | traces | traces |
| Sulphate of lime | 0.54 | traces |
| Water.... | 26.65 | 27.21 |
| Nitrogenous organic matter | traces | traces |
| | 100.88 | 99.13 |

* Comptes rendus, 1862, lv. 60.

LIME CRUCIBLES.

Lime heated *per se* is one of the most refractory substances known, and no temperature has as yet been attained which has caused it to exhibit the slightest indication of fusion.

Lime crucibles may be easily and rapidly made. Deville gives the following directions for the preparation of lime crucibles suitable for use in his furnace. A piece of well-burnt, slightly hydraulic lime is cut by means of a saw or knife into a rectangular prism with a square base, 3 or 4 inches on the side, and from 5 to 6 inches high. The edges of the prism are roughly rounded off, and a cavity of variable dimensions is bored in the centre. Thus prepared, they do not require stands. These crucibles should be closed with covers of lime cut in the same manner. In experiments, requiring a very high temperature, a small crucible of well-selected lime may be placed within another lime crucible; but when *the very highest temperature*, capable of being produced in this furnace, is required, only one crucible is used, of the dimensions above prescribed; and the diameter of the cavity should at the most not exceed $\frac{3}{4}$ or $1\frac{1}{4}$ inch, so that the thickness of the walls may remain from about $1\frac{1}{4}$ to $1\frac{1}{2}$ inch. The thickness of the bottom should be from 2 to $2\frac{3}{8}$ inches. The temperature should be gradually raised; and before the last portion of the fuel, which consists of "breezes" or small coke, is put in, care should be taken to ascertain that the crucible is not cracked.

The apparatus which Deville has devised and successfully introduced for melting large quantities of platinum by the combustion of coal-gas with oxygen, and which may be regarded as a crucible, consists of a rectangular box of cast-iron lined with small carefully cut rectangular pieces of lime. It is not practicable to use a clay crucible lined with lime when a high and long-continued temperature is required, for the obvious reason that at high temperatures combination would take place between the lime and clay where they came into contact, with the formation of a fusible product. This objection, however, might be obviated by lining the crucible first with carbonaceous matter and then with lime; and, long ago, plumbago crucibles lined with lime were employed in the Metallurgical Laboratory of the Royal School of Mines. The lime was slaked to powder, heated to redness, and when cold rammed down firmly round a wooden plug held upright in the crucible.

MAGNESIA CRUCIBLES.

Magnesia, like lime, has proved absolutely infusible at the highest temperatures attainable in furnaces or otherwise. It was stated by Giobert long ago, that bad clay might be rendered thoroughly refractory and suitable for glass-pots (i.e. pots in which glass is made) by intermixture with half or one-third (whether by weight or measure is not mentioned) of the magnesite from Baudissiero in Piedmont,

which is native carbonate of magnesia.⁹ Pott, also, recommended crucibles composed of two parts of clay and three of "burnt Spanish chalk," or one part of the former and two of the latter, which is silicate of magnesia resulting from the calcination of the hydrous silicate of magnesia or speckstein, of which the formula, according to Rammelsberg, is $6\text{MgO}, 5\text{SiO}_3 + 2\text{HO}$ [$3(4\text{MgO}, 5\text{SiO}_2) + 4\text{H}_2\text{O}$].¹ Regnault announced, at a meeting of the French Academy in 1866, that, more than 20 years previously, Thilorier had used crucibles of magnesia for the fusion of platinum, and had presented him with several of them, which did service in trials in the porcelain-kilns at Sèvres.² Caron had experimented on magnesia, with a view to its application as a refractory material for crucibles, fire-bricks, and the lining of reverberatory furnaces in which steel is to be melted, and made a communication on the subject to the French Academy in 1868, from which the following information has been abstracted.³ He used in his experiments native carbonate of magnesia from the island of Eubœa in the Ægean Sea, where it occurs in large quantity.⁴ The mineral from that locality is very compact and tolerably hard; it contains traces of lime, silica, and iron; and occasionally "serpentineous" matters (*matières serpentineuses*), and large plates (*plaques*) are disseminated through it, which would greatly lessen its infusibility. The flakes may be easily perceived, and separated, even on a manufacturing scale. The presence of these matters in fire-bricks might cause slight vitrification at the highest temperatures, but not any serious inconvenience.

Before trituration the mineral should be calcined in order to drive off its carbonic acid, as it is thereby rendered more friable and more easily pulverizable, and it then becomes possible to separate the intermixed serpentine and silica, which are not disintegrated by heat. After this treatment the magnesia is incapable of being agglomerated; but, even if it were otherwise, subsequent exposure to a temperature exceeding that of the calcination would produce enormous contraction, attended with cracks and distortion, which would forbid its use. Hence it is indispensable to expose the magnesia before it is moulded to a very high temperature, equal at least to what it is intended afterwards to support. After having been strongly heated, it is non-plastic, has a sand-like appearance, and does not cohere by compression. It acquires the last-named property by intermixture with magnesia calcined at a lower temperature; and, accordingly, such a mixture was employed by Caron in his experiments. The proportion between these two varieties of magnesia must necessarily vary with the temperatures to which they have been respectively exposed. Magnesia, which has been heated to the melting-point of steel, requires the addition of about $\frac{1}{4}$ (of its

⁹ Beiträge zur wissenschaftlichen Begründung der Glasmacherkunst; von Dr. A. F. Gehlen. Schweigger's Journal für Chemie und Physik, 1811, ii. 104.

¹ Ibid. p. 104.

² Comptes rendus, 1866, lxii. 296.

³ Ibid. 1868, lxvi. 839.

⁴ More than twenty years ago I saw a large quantity of this mineral at the Soda Works of Messrs. Chance, at Oldbury, near Birmingham, and brought away a specimen which I have still in my possession.

weight or bulk?) of that which has been heated to the lower degree. The mixture, so prepared, is to be moistened with from 10 to 15 per cent. of its weight of water, and, when intended for bricks, is to be strongly compressed in cast-iron moulds. A magnesia brick, produced as above described, hardens by drying in the air, and becomes more resisting by subsequent heating to redness. Small crucibles for the laboratory may be made in the same manner, but large ones cannot: the reason assigned by Caron being, that compression is difficult in the case of large masses, and that, as the magnesia adheres strongly to the sides of the mould, difficulty arises from that circumstance, in the case of large moulds with extensive surfaces.

The hardness which magnesia, after having been strongly heated and afterwards moistened with water, acquires on drying, is, doubtless, due to its hydration, though this change is stated by Caron not to be attended with any rise of temperature indicative of chemical combination. Magnesia thus consolidated only loses its water at a high temperature; and calcination, so far from causing its disaggregation, imparts to it a degree of hardness and resistance comparable with that of ordinary crucibles after firing. Magnesia intended for the manufacture of crucibles requires merely to be duly moistened with water, rammed (*tassée*) into moulds, dried, and afterwards fired. It happens, however, occasionally, either from the magnesia having been too much or too little hydrated, or from its containing too much siliceous matter, that the vessels, before or after firing (*cuisson*), do not possess the proper degree of solidity; in which case they require simply to be dipped in a saturated cold aqueous solution of boracic acid, dried, and fired as before. This operation does not make the magnesia more fusible, but only causes its particles to adhere more strongly together. Reverberatory furnaces for melting steel may be lined with a paste formed of the prepared magnesia and water, which will undergo the necessary drying and firing after the furnace is lighted, without any special precautions being required.

According to Caron, very pure, strongly calcined, and finely pulverized magnesia may, by admixture with water to the consistency of cream (*barbotine*), be employed to produce, by what is termed "casting" in the technical language of the potter, the most delicate and diaphanous crucibles, as well as the most complicated impressions.

Caron prefers crucibles of magnesia to those of lime, because the former may be kept a long time without undergoing change, whereas the latter cannot. He has had magnesia crucibles exposed during three years to air and moisture in his laboratory, and, on heating them gently afterwards, they were found to stand very well, without either contracting or becoming inconveniently distorted. He asserts that magnesia and lime possess in the same degree the property of not forming fusible substances with oxide of iron.⁵ But it has been previously stated that, when a mixture composed of lime and sesquioxide of iron, in certain proportions, is strongly heated, it melts.

⁵ Comptes rendus, 1866, lxii. 298.

With regard to cost, it may be mentioned, on the authority of Caron, that the native carbonate of magnesia, which formerly sold for 250 francs the 1000 kilogrammes (1000 kilogr. = about 1 ton) might be had in 1868 for 70 and 100 francs, when delivered at Marseilles and Dunkirk, respectively.

Not long ago Messrs. Émile Muller and Co., of Ivry, near Paris, entered upon the manufacture of magnesia crucibles; and I received a communication from them on the subject, which I submitted to Sir Joseph Whitworth, who forthwith ordered samples of these crucibles for trial in the process of melting steel, and who has favoured me with the following account of his experience of their use (June 5, 1871.)

Three or four small magnesia crucibles supplied by the above-named firm stood the heat well, so long as they were empty and were kept in the furnaces. There appeared, however, to be but little cohesion between the particles of magnesia, and the crucibles always fell to pieces when taken out of the fire. About 15 months since Mr. Hoyle, an agent of Sir Joseph Whitworth, mentioned the circumstance to Messrs. Muller and Co., who then admitted that they did not consider the material well adapted for steel-melting in pots, and stated that they preferred rather to use it as a lining for Bessemer-converters, or the hearths of Siemens' furnaces intended for the fusion of steel, as in the former case it would be supported by the sides of the converters, and in the latter by the bottom of the furnace. They were engaged at that time in making magnesia linings for some Bessemer-converters for the Creusot Works. As magnesia is so highly refractory, it would be an excellent *neutral* material for steel-melting pots, if they could be made sufficiently coherent and resisting.

I have lately had a circular from Muller and Co. in which it is stated that they manufacture magnesia-lined furnaces for the fusion of platinum by coal-gas and oxygen, and "magnesia chalks" (*crayons de magnésie*) to receive the oxy-hydrogen flame in order to produce intensely brilliant and powerfully actinic light.

MOULDS FOR SMALL CRUCIBLES; COVERS FOR CRUCIBLES; CRUCIBLE LININGS, STANDS, AND TONGS.

MOULD FOR MAKING SMALL CRUCIBLES.

More than twenty years ago my friend Rinmann, of Sweden, presented me with a mould which he informed me had been invented by his countryman, Gustav Ekman, and was employed in Sweden for making small crucibles used in assaying iron-ores.* Ever since, I

* It is described and figured in the *Jern-Kontorets Annaler*, 1852, p. 56.

have employed crucibles of this kind with great advantage, not only

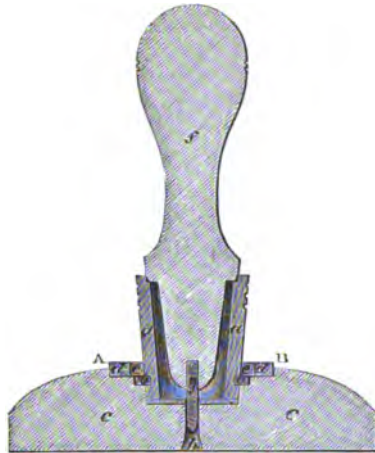


Fig. 14. Mould for making small crucibles.
Vertical section through the centre.



Fig. 15. Mould for making small crucibles.
Horizontal section on the line A B, fig. 14.

in assaying iron-ores, but also in metallurgical experiments of various kinds. A description of the mould has appeared in Swedish, and subsequently in German. The following description of it includes certain alterations in detail, which, in the course of long practice in our assay-laboratory, it has been found expedient to adopt. Fig. 14 is a vertical section through the centre; fig. 15 is a horizontal section on the line A B, fig. 14. All the figures are drawn to a scale of $\frac{1}{2}$. *a* is a short hollow slightly conical ring or cylinder open at both ends, made of gun-metal. *bb* are short pins of iron inserted one in each side of *a*, near the bottom or narrower end. *c* is a round block of wood, in the centre of which, on the upper surface, is a circular cavity large enough to receive the lower end of *a*, and to allow the projecting pins, *bb*, to turn round in the cavity; through the middle of this cavity is a hole, *h*, and upon the bottom of it lies a disc of

gun-metal, as seen in fig. 14, which also has a hole in the centre of the same size as *h*. Around the edge of this cavity is screwed a flat ring of brass, *dd*. *ee* are notches in the brass ring to allow the pins *bb* to pass through, so that *a* may be turned into the position seen in fig. 15, when the pins *bb* will hold it firmly under the projecting edge of the ring of brass. *f* is a circular wooden plug, similar in form to the plug *f'*, fig. 16, without the oblique groove, *i*, but having an iron pin, *g*, fixed in the bottom of it, as shown in fig. 14; by means of this pin the plug is kept upright exactly in the axis of the mould. Fig. 16 shows another wooden plug, *f'*, without a pin, but having an oblique groove, *i*. The inner surface of *a* is very slightly oiled, and also the outer surface of *f*, where it passes into *a*. *a* being adjusted, as shown in fig. 15, a small lump of *well-tempered* clay is put into *a*, when the plug *f* is forced down by hand and turned round; the excess of clay escapes from the upper edge of *a*; *f* is now withdrawn, and a small bit of clay is dropped in,



Fig. 16.
Wooden plug.

when f' is forced down and turned round and round, by which means the hole in the bottom of the crucible caused by the pin g is filled up, the excess of clay escaping by the groove i . f' is then taken out, and a , with the contained crucible, detached from c . The crucible may be removed from a by being pushed gently upwards with a circular piece of metal or wood applied to the bottom. The mixture we usually employ consists of about two measures of raw and one of burnt clay. The crucibles, before use, are dried and gradually heated to redness in a muffle.

CRUCIBLE COVERS.

The mouth of the crucible may be fitted with a cover composed of the same material as the crucible itself. Such covers may be easily made by cutting or stamping them out of the clay mixture rolled out upon a flat surface. For the small crucibles prepared in the mould, of which a description has been given, we are accustomed to make nicely fitting covers in a mould of which the construction is shown in vertical section through the centre, in the annexed woodcut, fig. 17. a is a cylindrical piece of wood, upon which fits a movable hollow cylinder of brass, $b b$, perforated laterally with several holes, $c c$, &c.; d is a cylindrical plug of wood hollowed out at the bottom, as represented in the woodcut; this plug fits into the brass cylinder $b b$, upon the top of which it rests, so as to leave a space, e . A small lump of clay having been put into the cylinder, the plug d is pressed down and turned round, when a cover is moulded in the space e , the excess of clay being expelled through the holes, $c c$, etc. The plug is first withdrawn, and then the cylinder, after which the cover, which is formed with the top or flat side downwards, may be detached and left in a warm place to dry.

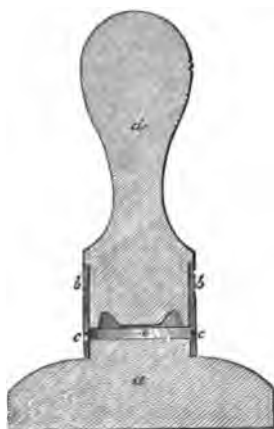


Fig. 17. Mould for making covers.
To the scale of $\frac{1}{2}$.

Pieces of old crucible or of thin fire-bricks, termed *split-bricks*, may also be conveniently used for covering crucibles, in which case it may be desirable to plaster the mouth over with fire-clay.

Covers are supplied to order by crucible makers.

CRUCIBLE LININGS.

Crucibles may be lined, i. e. coated internally, with various kinds of material, such as carbonaceous matter, silica, alumina, etc. The French designate any such lining by the substantive *brasque*, and the operation of lining by the verb *brasquer*; and as these words are short and definite in meaning, the word *brasque* will be used in this work both as a substantive and a verb, in the same sense as the French words. When the word is hereafter employed, without specifying the nature of the lining, it will indicate a lining of charcoal powder.

LINING OR BRASQUING CRUCIBLES WITH CARBONACEOUS MATTER.—This is done when it is necessary to protect the crucible from the corrosive action of matter which may be heated in it, or when a small quantity of a metallic compound is to be reduced, of which every particle of the metal must be collected, as in the assaying of iron-ores in the little crucibles just described, when not more than 10 grains of ore are operated upon at a time. The minutest portions of iron, which may become entangled in the lining, may be separated by gently crumbling it to powder and applying the magnet. In the case of a difficultly reducible oxide, like protoxide of manganese, the oxide would powerfully corrode an earthen crucible at a temperature far below that at which reduction occurs; but a carbonaceous lining effectually prevents contact between the oxide and the sides of the crucible. The atmosphere of a crucible so lined will always be *reducing* at a high temperature, owing to the *carbonic oxide* which obviously must be present. When the lining is sufficiently thick, and the reduction of a metallic oxide is desired, it may not even be necessary, in certain cases, to previously mix the oxide with carbon. Such a lining may

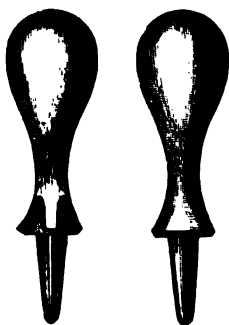


Fig. 18. Boring-tool. Fig. 19. Smoothing-tool.
The boring and smoothing parts are made of gun-metal, and the handles of wood.



Fig. 20. Vertical section of a lined crucible in its finished state.

(These three figs. are drawn to the scale of $\frac{1}{4}$ of the actual size.)

also tend to prevent the crucible from sinking down upon itself, when softened by intense heat and exposed to the pressure of the fuel. Various kinds of carbonaceous matter may be employed, according to circumstances. In the case of very small crucibles, charcoal powder, mixed with sufficient gum-water, starch, paste, or treacle, just to make it cohere by pressure, should be gently rammed in so as entirely to fill the crucible. A cavity may then be made in the charcoal by boring with an instrument of the form shown in fig. 18, and the surface of the cavity so made may be afterwards rendered perfectly even and smooth by pressing down an instrument of the form shown in fig. 19, and turning it round. A section of a crucible thus prepared is represented in fig. 20. The diameter of the cavity should gradually diminish from top to bottom. For some time we used lamp-black, which has the advantage of being easily and solidly compressible without any addition; but we abandoned it on account of the impurity of the commercial article, which contains sulphates. The charcoal lining above described answers perfectly; but we have occa-

sionally replaced it by little crucibles fashioned out of charcoal made from a dense wood like box or ebony. Large crucibles may be coated internally with the same mixture of charcoal as is used for the small ones; but a mixture of anthracite powder, or the powder of gas-retort carbon, and gas-tar answers still better. The carbon

crucible, for such is the lining, may be conveniently made in a separate mould, and afterwards carefully dried, then imbedded in anthracite powder or coke-dust in a closed iron box, and gradually heated to redness. The box should have an overlapping lid, and, after heating, should not be opened until the contents are cold. When gas-retort carbon is used, a vessel may be obtained in this way which, when struck, rings like a piece of metal. One of these vessels may be dropped into a clay crucible just large enough to receive it, and, when properly treated, it may be used more than once.

LINING OR BRASQUING CRUCIBLES WITH OTHER THAN CARBONACEOUS MATTER.—Berthier states that he has occasionally lined crucibles with silica, alumina, magnesia, or chalk, previously moistened with water so as to make them sufficiently cohesive; and that a thin lining of chalk renders earthen crucibles less permeable to molten litharge.⁷

CRUCIBLE STANDS.

When crucibles are heated in a common air-furnace, it is desirable to support them on stands about 2 or 3 inches above the bars. Such stands may either be expressly moulded out of the same mixture as that of which clay crucibles are made, or fashioned out of bits of fire-brick, chipped to a convenient shape and size.

Stands are supplied to order by crucible makers.

TONGS FOR CRUCIBLES.

The annexed engravings are from photographs of various kinds of tongs for manipulating with crucibles. They are made of wrought-iron. Fig. 21 represents such as are adapted for small crucibles; fig. 22, such as are used by Cornish copper-assayers, the ends consisting of rectangular pieces of iron; fig. 23, such as are of general utility, but, as the leverage is great, they must be used with care; fig. 24, such as are used for the large crucibles employed by brass-founders. When the last-named tongs are used to take out of the furnace a large crucible containing a heavy weight of metal, it is customary to slide an iron ring over the handles, in order to prevent the crucible from slipping away.

Scale of $1\frac{1}{4}$ inch
to 20 inches.

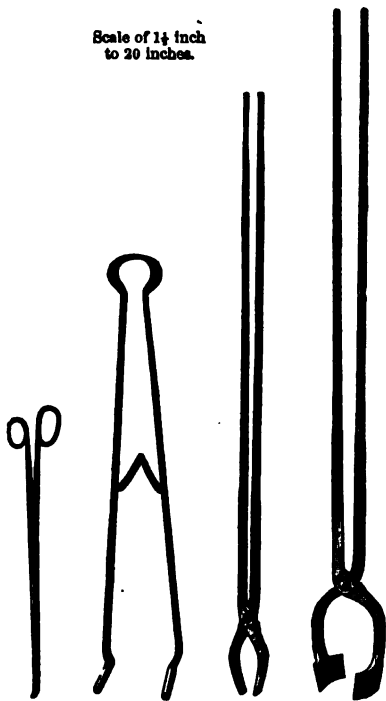


Fig. 21.

Fig. 22.

Fig. 23.

Fig. 24.

Tongs used for crucibles.

⁷ *Traité des Essais*, i. 83.

FURNACES FOR CRUCIBLES.

In this place will be given a description of little blast-furnaces suitable for experiments in small crucibles, when a very high temperature is required. An air-furnace, well adapted for ordinary experiments, will be found described in the article in this volume on Copper-assaying.

SEFSTRÖM'S BLAST-FURNACE.

For this useful furnace we are indebted to Sefström, the well-known Swedish metallurgist. It is extremely convenient for easily and rapidly producing high temperatures. It may be made very portable, and at a cost only of a few shillings. The annexed woodcut, fig. 25, represents a vertical section through the centre of a small

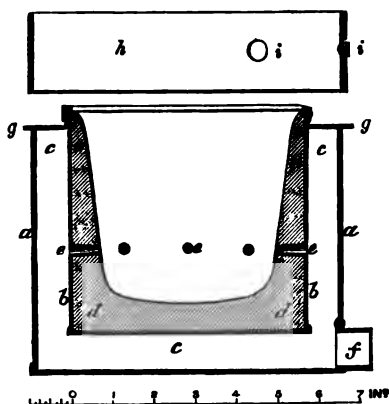


Fig. 25. Sefström's blast-furnace.
Vertical section through the middle.

furnace of this kind, in which the crucibles, made as described at p. 137, are heated. During many years I have employed this furnace with great advantage in various metallurgical experiments; and I can confidently recommend it to persons who may travel in distant parts and desire to take with them a furnace not exceeding the size of a hat. It is cylindrical, is made of sheet-iron, and consists of an outer cylinder, *a a*, closed at the bottom and round the circumference, except at *f*, where a short pipe is inserted for the entrance of the blast; and of an inner cylinder, *b b*, completely closed at the bottom, and fixed in the position shown in the woodcut by a rim, *g g*. There is thus formed a hollow space or chamber, *c c c*, into which air can be blown through the orifice *f*. In the inner cylinder, *b b*, are eight small holes, *e e e*, etc., at the same height from the bottom, and at equidistant spaces. Into each of these holes is inserted a small nozzle of sheet-iron, tapering inwards, $\frac{3}{8}$ of an inch in diameter at the small end. The interior of the inner cylinder is lined with a suitable mixture of fire-clay, *d d*, which is represented by the shading of sectional lines. Any cracks which may occur during the drying of the clay must be filled up with the clay mixture, so that the lining may be rendered compact. It will be observed that the inner cylinder projects somewhat above the rim *g g*. Round this projecting part a hoop of sheet-iron, *h*, is dropped so as to rest on the rim *g g*, by which means the furnace may be heightened, and space provided in which fuel may be piled. The hoop *h* is formed by bending the sheet-iron and overlapping the ends, in one of which there are two small holes, *i i*, while to the other is fixed a button, which may be fitted at pleasure into either of those holes. The

hoop may thus be made greater or less in diameter, so as to be placed either round the top of the inner cylinder above *g g* or, when the furnace is not in use, round the outer cylinder *a a*. Charcoal is the fuel usually employed, and it should be broken into pieces about as large as walnuts. A small pair of double bellows is required to produce the blast. Four of the small iron-assay crucibles of Ekman, or even more, may be heated at a time in this furnace. Sefström's furnaces may be made of much larger dimensions when portability is not an object. If it is desired to ascertain the pressure of the blast, a short bit of wrought-iron pipe may be inserted in the outer cylinder just below the top to receive a little glass-tube bent in the form of a common U-shaped gauge containing either water or mercury. The pressure of the blast may be regulated by adjusting a stop-cock to *f*, fitted to receive the nozzle of the bellows.

In the woodcut the hoop *h* is shown in section, with the button inserted in the first hole; that is, in the position which it occupies when the hoop is put round the body of the furnace.

DEVILLE'S BLAST-FURNACE.*

In the Metallurgical Laboratory of the Royal School of Mines we have used this furnace, and found it very convenient for obtaining high temperatures. Deville has melted platinum in it. In fig. 26 it is shown in vertical section through the centre, and in

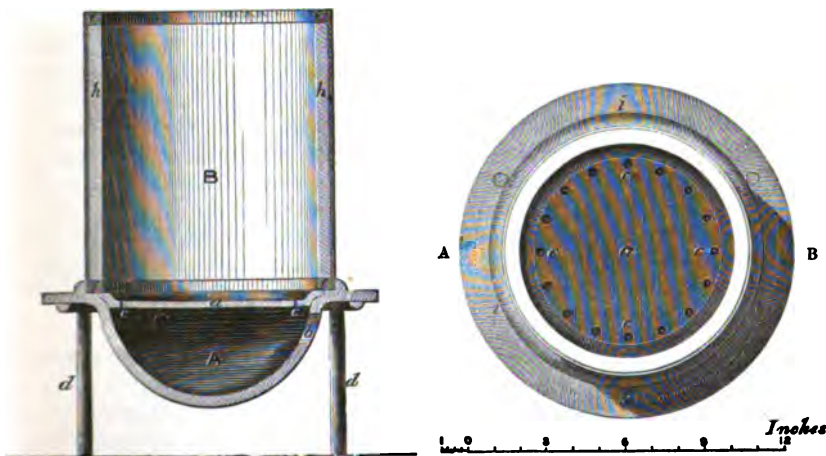


Fig. 26. Deville's blast-furnace. Vertical section on the line *a a*, fig. 27.

Fig. 27. Deville's blast-furnace. Plan.

fig. 27 in plan. *A* is a vessel of cast-iron, having a circular hole, *b*; it is supported by a tripod, of which *d d* are legs; *a*, a circular cast-iron plate, which forms a cover to *A*; in *a* is a series of 16 holes, *c c*, etc., equidistant from the centre. *B* is a cylinder of sheet-iron,

* *Ann. de Chim. et de Phys.* s. 3, 1856, xlv. 190.

strengthened at the top and bottom by two rings of wrought-iron, *ee, ff*; within, it is lined with a mixture of burnt and raw fire-clay, *h*, to the thickness of the rings *ee, ff*; any cracks which may be formed during the drying of the clay lining must be filled up. The blast enters at *b*, fig. 26, and rises through the 16 holes in the plate *a*. The crucible is placed on a stand in the centre. The construction of this furnace is such as to produce an intense heat over a wide surface, but within a very limited height from the bottom. Coke, not too dense, of about the size of walnuts is an excellent fuel for this furnace. Deville uses cinders or "breezes" from the ash-pit of a furnace in which the non-caking coal of Charleroi is burnt; the "breezes" are sifted and, thus obtained, vary in size from a pea to a hazel-nut. Ignited charcoal is first introduced to the height of 2 or 3 inches, then pieces of coke of the size of walnuts, and lastly "breezes." According to Deville's experience, at the high temperatures which he obtains, and which he designates by the term *blue-heat*, the best earthen crucibles become as liquid as glass. He accordingly prepares crucibles of carbon, lime, or alumina for this furnace, in the manner already described.

FIRE-BRICKS.

The term *fire-brick* is applied to bricks capable of resisting high temperatures, whether made of fire-clay or other refractory material. They need only be used in those parts of furnaces where the heat would be sufficient speedily to destroy ordinary bricks, the application of which should therefore be restricted to the external or cooler parts. They are made of varying shapes and sizes to suit the manifold requirements of the furnace-builder. In large establishments, such as the Ironworks of South Wales, they are made on the spot. Much of what has been previously stated concerning crucibles will equally apply to fire-bricks.

The qualities required in fire-bricks are as follow :—

They should not melt, or soften in a sensible degree, by exposure to intense heat long and uninterruptedly continued.

They should resist sudden and great extremes of temperature.

They should support considerable pressure at high temperatures without crumbling.

They may be required to withstand, as far as practicable, the corrosive action of slags rich in protoxide of iron or other metallic oxides.

Experiment on the large scale is essential to the formation of a correct judgment as to the power of resisting pressure at high temperatures.

The clay of which fire-bricks are made is ground between rolls or under edge-stones, and afterwards suitably kneaded by treading

with the naked feet after the addition of water; or it is passed through a pug-mill. In some establishments the powder of burnt clay is used in admixture with raw clay. The tenacity of a clay is much affected by the amount of *free silica* which it contains: when it is naturally too tenacious to admit of being directly applied, the right *temper* may be readily produced by the addition of burnt clay in coarse powder. In setting fire-bricks, fire-clay should be used instead of lime-mortar.

CLAY FIRE-BRICKS.

STOURBRIDGE CLAY FIRE-BRICKS.

Stourbridge bricks have long been highly valued for their refractory quality, and exported to various, even far remote, parts of the world. Similar bricks are also manufactured in other localities in the United Kingdom. All these bricks have a pale-brownish colour. Sometimes they are copiously mottled with dark spots, caused by particles of iron-pyrites in the clay, and the production therefrom of oxide of iron by oxidation during the operation of burning the bricks.

They are fashioned by hand in moulds similar to those used in the manufacture of common bricks. But moulds of brass or other metal, and even of glass, have been substituted for moulds of wood in some localities. Cowen states⁹ that in the north of England (Northumberland and Durham) attempts have been repeatedly made to produce fire-bricks by machinery, yet without success; whereas in Wales such an application of machinery has succeeded, owing, it is suggested, to the Welsh clay differing in quality from that of the north. I communicated with my friend Mr. Isaac Lowthian Bell on this subject, and have received from him the following information. "I called on Mr. Cowen, the writer of the paper on the manufacture of fire-bricks to which you refer, and he informs me this article continues, and in his opinion always will continue, to be made by hand. Machine-made bricks, he says, are always more compact than those made in the old way, and this he considers a defect." (June 7, 1871.)

FOREIGN CLAY FIRE-BRICKS.

Brongniart mentions several kinds of French fire-bricks as being in the highest degree refractory, namely, those from *Mouchy*, Saint-Éloy (Oise), manufactured by Deyeux; those from *Septeuille*, near Provins; and those from *Saint-Vallier*, near Oriol. He states that all these bricks were exposed to the highest temperature of a porcelain-furnace, but protected from the direct action of the potash contained in the ashes—wood being the fuel—and that they suffered no change; whereas, Stourbridge bricks exposed to exactly the same conditions became red-brown, and were completely softened.¹ It appears to me doubtful whether in that trial Stourbridge bricks of the best quality were used.

⁹ *Op. antea cit.*
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¹ *Traité des Arts céramiques*, 1844, i. 341.

SILICA FIRE-BRICKS.

BRITISH SILICA FIRE-BRICKS.

DINAS FIRE-BRICK.

This brick consists almost entirely of silica. It was invented by the late Mr. W. Weston Young, a land-surveyor, of Newton-Nottage, Glamorganshire, whose original documents on the subject have been placed at my disposal by his great-nephew, Mr. Edward Young. A company was established for the manufacture of these bricks in 1822 by Mr. Young, who thus describes the history of his invention:—"The material at the Dinas (the well-known rock of that name in the Vale of Neath),² from which we procure it, is nearly pure siliceous; but, from its lying on the limestone and occasionally intermixing with it, there is, taking the average of the general working, perhaps, about 5 per cent. of calcareous matter and 1 per cent. of metallic, either iron or copper. Its use as a sand was discovered about 40 years ago,³ when the fine of it was taken to one of the copper-works and used as a cement, and for mending their furnaces while at work, by placing it with a long iron-handled ladle or spade where the wash of the metal had destroyed the brick; and, from its remarkable property of swelling in high heats, it fixed itself firmly. It gradually gained from one copper-work to another till its use became general: in fact, they are not able to find any other sand that will answer the purpose so well. Its fire-proof qualities being known, many attempts were made to produce a brick from it; but all the common combinations of different clays, etc., failed. About 14 years ago I became acquainted with it, and soon after devised a method of producing a brick from it of very extraordinary fire-proof qualities. When set in its own cement, for very high and long-continued heats it certainly will exceed in duration any other known brick. It does not suit every situation, as, in fact, no fire-brick will: the nature of it at once tells you it must not be placed near alkaline substances; neither will the effluvia from some lead-ores suit it. Perhaps it does not exceed Stourbridge (brick) for grates; but for the body of furnaces of most kinds it exceeds, as said before, that and every other known brick in duration. The manner in which the brick is made gives it a rough coat compared with most others; indeed, it is peculiar in this respect; but, as it is made in machines perfectly square, all the works here prefer it with its rough coat; they say it sits better in the work, and they have now had more than 12 years' experience. This brick ought to be kept dry if possible, for, being open in its texture, it imbibes moisture freely. The fire-place, roofs, sides, and bridge of the furnace, also the lower part of the stack, should be built

² This rock is believed to be the millstone grit of the Carboniferous System, and the geological equivalent of the bed, termed "ganister" at Sheffield, which is used as a lining for the Bessemer-converter, as well as for the manu-

facture of fire-bricks now carried on in that locality.

³ The description is not dated, but it was written twelve years after the bricks had come into use.

of Dinas; the back part and the remainder of the stack will do best of the other kind (similar to Stourbridge in quality); slabs for leaving the flues and doors are also best made of this material. The appearance of the Dinas brick is peculiar in colour and the roughness of its surface."

The mode of making the Dinas brick was long kept rigidly secret, and until a few years ago it was not generally known.

The material, or, as it is locally named, "clay," of which this brick is made, is found at several places in the Vale of Neath, some of which I visited with Mr. E. Young in 1859. It occurs in the state of rock and disintegrated like sand. Its colour, when dry, is pale-grey. The rock, when not too hard, is crushed to coarse powder between iron rolls. By exposure to the air the hard rock becomes somewhat softer, but some of it is so hard that it cannot be profitably employed. The composition of Dinas "clay," from two localities in the Vale of Neath, was found to be as follows:—

COMPOSITION OF DINAS "CLAY."

| | I. | II. |
|-------------------------|-------------|-------------|
| Silica | 98·31 | 96·73 |
| Alumina | 0·72 | 1·89 |
| Protoxide of iron | 0·18 | 0·48 |
| Lime | 0·22 | 0·19 |
| Potash and soda | 0·14 | 0·20 |
| Water combined | 0·85 | 0·50 |
| | <hr/> 99·92 | <hr/> 99·49 |

The analyses were made in my laboratory by W. Weston. No. I. was rock of medium hardness, which I obtained near Pont Neath Vaughan, on the occasion of my visit with Mr. E. Young; and No. II. was sent to me from the same locality, though not from the same mine. The powder of the rock is mixed with about 1 per cent. of lime, and sufficient water to make it cohere slightly by pressure. This mixture is pressed into iron moulds, of which two are fixed under one press, side by side. The mould, which is open at the top and bottom, like ordinary brick-moulds, is closed below by a movable iron plate, and above by another plate of iron, which fits in like a piston, and is connected with a lever. The machine being adjusted, the coarse mixture is put into the moulds by a workman, whose hands are protected by stout gloves, as the sharp edges of the fragments would otherwise wound them: the piston is then pressed down, after which the bottom plate of iron on which the brick is formed is lowered and taken away with the brick upon it, as it is not sufficiently solid to admit of being carried in the usual manner. The bricks are dried on these plates upon floors warmed by flues passing underneath; and when dry they are piled in a circular closed kiln covered with a dome, similar to kilns in which common fire-bricks are burned. About 7 days' hard firing are required for these bricks, and about the same time for the cooling of the kiln. One kiln contains 32,000 bricks, and consumes 40 tons of coal, half free-burning and half binding. The

price (1859) is 60s. per thousand for common-sized bricks. They are manufactured of various shapes and sizes, to suit the furnace-builder.

The fractured surface of these bricks is uneven, showing coarse irregular white particles of quartz, surrounded by a small quantity of light-brownish yellow matter. The lime which is added exerts a fluxing action on the surface of the fragments of quartz, and so causes them to stick together. These bricks expand by heat, whereas bricks made of fire-clay contract. On this account they are stated to be advantageous for the roofs of reverberatory furnaces, and in all parts where a solid and compact lining is needed. From their siliceous nature it is obvious that they should not be exposed to the action of slags rich in metallic oxides.

My friend Mr. W. Edmond, Manager of the Mines-Royal Copper Works, informs me (December 1871) that good Dinas bricks are manufactured by J. B. Jenkins, Bryn Llyfi, St. Thomas, Swansea, and by Fredricks and Jenner, Glyn-Neath, Glamorganshire. Silica bricks, it is announced (1871), are manufactured by Émile Muller and Co., Ivry, Paris.

DEVONSHIRE FIRE-BRICKS.

The waste residue, which is obtained in the preparation of china-clay, from the weathered and decomposed feldspar of granite, seems mainly to consist of small angular fragments of white quartz, and is the chief constituent of these fire-bricks. It is mixed with a small quantity of what is called the poorer kind of china-clay, and a suitable proportion of water, and the mixture is passed through a pug-mill and moulded into bricks in the usual manner by hand. The bricks are carefully dried and fired in kilns. At Woolwich Arsenal these bricks are used in reheating-furnaces, in which a temperature sufficient to heat wrought-iron to the welding-point is required. They are manufactured by Messrs. Martin Brothers, at Lee Moor, Plympton, Devonshire, and are sold under the name of Lee Moor Porcelain Fire-Bricks. They are reported to stand well. On the exterior they have a pale-brown tint, and are freckled with brown spots; they are superficially glazed and cracked. Their fractured surface has a prevailing light straw tint, and much resembles that of Dinas brick, presenting numerous fragments of comparatively white quartz cemented together with light straw-coloured matter, and freckled throughout with spots varying in colour from brown to brown-black.

For the following analysis of a Lee Moor fire-brick, I am indebted to my friend Mr. Abel, Chemist to the War Department.

COMPOSITION OF A LEE MOOR FIRE-BRICK.

| | |
|---------------------------|-------|
| Silica | 75·04 |
| Alumina | 21·25 |
| Sesquioxide of iron | 1·95 |
| Lime | 0·41 |
| Magnesia | 0·37 |
| Potash | 0·83 |
| Soda | 0·09 |
| | <hr/> |
| | 99·94 |

FOREIGN SILICA FIRE-BRICKS.

STYRIAN FIRE-BRICKS.

These bricks consist of silica, intermixed with just sufficient fire-clay to impart the requisite plasticity for moulding, and the requisite cohesion by burning. A detailed account of their manufacture has been published by J. Kherns, a metallurgist at Kapfenburg, in Styria.⁴ The silica is used in the state of powder, which has passed through a sieve of about 60 meshes to the square inch (nearly the same as the English inch); and it should be prepared from quartz as free as possible from mica, feldspar, iron, and other foreign matter; in short, the purest that can be obtained. It is heated during 10 or 12 hours in kilns, and at last, when it has become bright red-hot, it is thrown into water, in order to render it friable, and to separate, by means of suitable washing apparatus, the ashes of the fuel, as well as other impurities which may be thereby disclosed. It is next hand-picked, and the purest lumps are reserved for the most refractory bricks. The lumps are crushed by stamps or tilt-hammers, and sifted; and, when necessary, it may be treated with dilute hydrochloric acid, and afterwards washed with pure water.

The composition of the fire-clay, which serves as a binding-material, is not stated. The clay is ground and passed through a sieve of 600 meshes to the square inch.

Three qualities of fire-bricks are made. The mixture for the best quality, in which only the purest quartz-powder is used, contains about 6 per cent. by measure of one kind of clay, and about 7 per cent. of another. In the mixture for the second quality, either somewhat impure quartz is used, or old burnt bricks of the first quality, with the addition of about 6 per cent. of raw clay; and the third quality is made of a mixture of the powder of old bricks of the second and third qualities, with 10 per cent. by measure of raw clay. The ingredients are intermixed in a dry state, and kneaded after the addition of a proper quantity of water. The best bricks are made with a press in cast-iron moulds of the usual form, while the bricks of inferior quality are made by hand in sheet-iron moulds, the mass being stamped down by means of a short rammer. The bricks are carefully dried, and burnt for about 70 hours in closed kilns, which contain about 2500 bricks—each 12 inches long, 6 wide, and 3 thick—and of which the interior, towards the last, becomes white-hot.

Fire-bricks, manufactured as above described, are said to be suitable for Siemens' regenerative steel-melting furnace, in which a temperature sufficient to fuse wrought-iron is attained.

⁴ *Zeitschrift des österreich. Ingenieur- und Architekten-Vereins*, 1865, No. 12. An abridgment of Kherns's description is given in the *Berg- und hüttenmännische Zeitung*, 1866, p. 213, and in Wagner's

Jahresbericht for 1866, xii. 337. The original paper contains minute details of the mode of manufacturing these bricks, and is illustrated with drawings to scale of the implements and kilns which are used.

**OTHER FIRE-BRICKS FROM VARIOUS LOCALITIES, BRITISH
AND FOREIGN.**

COMPOSITION OF FIRE-BRICKS FROM DIFFERENT LOCALITIES.

| | I. | II. | III. | IV. | V. | VI. | VII. |
|------------------------------|--------|--------|------|------|--------|------|------|
| Silica | 63·09 | 84·65 | 88·1 | 84·0 | 88·43 | 69·3 | 77·6 |
| Alumina | 29·09 | 8·85 | 4·5 | 14·1 | 6·90 | 28·5 | 19·0 |
| Lime | 0·42 | 1·90 | 1·2 | 0·7 | 3·40 | .. | .. |
| Magnesia | 0·66 | 0·85 | .. | .. | trace | .. | 2·8 |
| Sequoioxide of iron | 2·88 | 4·25 | 6·1 | 0·5 | 1·50 | 2·0 | 0·3 |
| Potash | 1·92 | .. | .. | .. | .. | .. | .. |
| Soda | 0·81 | .. | .. | .. | .. | .. | .. |
| Titanic acid | 2·21 | .. | .. | .. | .. | .. | .. |
| | 100·58 | 100·00 | 99·9 | 99·3 | 100·23 | 99·8 | 99·7 |

I. By Riley. Communicated to the Author.—II. Richardson, Knapp's Technology, Trans. ii. 481.
III. IV. V. Napier, Phil. Mag. s. 4, iv. 348.—VI. VII. By Berthier, *Traité des Essais*, i. 67.

I. From Dowlais, South Wales. The clay of which the brick was made is known as the "little vein west clay."

II. Windsor bricks. These bricks are red. They are pretty refractory, and admit of being easily sawn into pieces, so that they may be conveniently used in various metallurgical experiments. They are extensively employed in the construction of gas-retort furnaces. There are two kinds, known in commerce as "P.P. Rubbers" and "P.P. Fire-bricks." They are made at Chalfont St. Peter's, Buckinghamshire.⁵ Bricks of a similar kind, it is stated, are manufactured at Ewell in Surrey, from a greenish clayey sand, which forms the lowest of the Woolwich and Reading beds.⁶

III. From Flintshire. This brick is made at Buckley, in Flintshire, and hence is known by the name of "Buckley brick"; it is stated to be used in the construction of furnaces and chimneys in copper-works of Wales in parts exposed to great heat and currents of air; but not where melted matter can come in contact with it. It is also used in lead-smelting furnaces in Flintshire. It is coarse-grained in fracture, of which the prevailing colour is brown-red.

IV. From Lysnewydd, S. Wales: it is used for fire-places and hearths.

V. From Pembroke: it is used in copper-works. The analysis is by Cameron, formerly Chemist at the Spitty Works, near Swansea.

VI. From Creusot, France: it is used for blast-furnaces.

VII. From Provins, France: it is used for reverberatory furnaces.

⁵ This statement is made on the authority of Messrs. Eastwood, Belvedere Road, Lambeth, from whom these bricks are obtained for use in the Metallurgical

Laboratory of the Royal School of Mines.

⁶ This information has been communicated by Whitaker, of the Geological Survey of England.

BLUE-BRICKS.

Although these bricks are not refractory, yet I mention them because the mode of glazing them is interesting in a metallurgical point of view. They receive their name from the dark-grey glaze on their surface. In Staffordshire the clay of which these bricks are made occurs in the Permian beds, about 100 yards above the Coal-measures. The thickness of the clay ranges from 6 feet to 30 yards. The clay which is employed for the best blue-bricks is usually of a dark-red colour. Clay from different parts of the seam *sinks*, i.e. shrinks differently, in burning, the best clay to the extent of about $\frac{1}{4}$. The bricks are moulded in the same manner as common bricks. The deep-blue colour of the bricks is obtained by selecting suitable clay, by regulating the time of burning—which is generally about 60 hours—and by sprinkling over the bricks, before firing, finely sifted “iron swarf,” the substance produced by the wear of the siliceous grindstones employed in grinding gun-barrels, etc., and which consists of an intimate mixture of fine particles of stone and iron; or, except for the best bricks, cheaper materials may be used, namely, the ferruginous substance, like yellow ochre, which settles at the bottom of gutters conveying the water from the mines, and which is scraped up, dried, and riddled; or “rusty ironstone”—a soft rocky clay-ironstone often found in surface clay—which is pounded and passed through a sieve. Glazing is effected by throwing common salt into the fire-holes of the kiln as soon as the burning is completed, about 1 cwt. of salt being required for each kiln full of bricks. The bricks are fired in closed circular kilns, about 14 ft. in diameter, and holding about 10,000 or 15,000 bricks or tiles. In firing, the iron becomes oxidized, and combines with the silica of the brick to form silicate of protoxide of iron. Blue-bricks are used by engineers for special purposes.

PARTICULAR APPLICATIONS OF SILICA.

Silica is extensively used by the metallurgist, both in the state of sand and sandstone.

REVERBERATORY FURNACE BOTTOMS.

The bottoms of the reverberatory furnaces, in which the operations of smelting and refining are effected in the copper-works at Swansea, are made of sand. Great accumulations of blown-sand occur on the neighbouring coast suitable for this purpose; and some of the best quality, I am informed, is met with at Briton-Ferry, near Neath. I received from the late Mr. F. F. Bankart, formerly of the Briton-Ferry Copperworks, a sample of this sand, which has been analysed in my laboratory by W. Weston. It has a brownish-yellow colour, and contains minute fragments of shells. Le Play has also determined the composition of similar sand from Swansea. The analyses of Weston and Le Play are as follow:—

COMPOSITION OF THE SAND USED FOR THE BEDS OF COPPER FURNACES.

| | I. Weston. | II. Le Play. |
|---------------------------------------|---------------|-----------------|
| Silica | 87·87 | 86·0 |
| Alumina | 2·13 | 1·6 |
| Sesquioxide of iron..... | 2·72 | 1·2 |
| Lime | 8·79 | 5·7 |
| Magnesia | 0·21 | 0·8 |
| Carbonic acid and a little water | 2·60 | 4·5 |
| | <u>99·32</u> | <u>99·8</u> |

These results show that the composition of the sand is more uniform than might have been expected, as the sample on which Weston operated was obtained in 1859, more than ten years after Le Play's. The source of the lime was the intermixed shell substance, which consists almost wholly of carbonate of lime. At a high temperature the lime would, as in the case of the Dinas brick, tend to cement the siliceous particles of the sand together. Hence the suitability of the sands in question for copper-furnace bottoms is probably due to the presence of calcareous matter.

BLAST-FURNACE HEARTHES.

Silica in the form of sandstone is an excellent material for the hearths of blast-furnaces, in which iron is smelted.

CASTING-SANDS.

Kampmann⁷ has given the following analyses of sands employed for moulds in various foundries:—

COMPOSITION OF VARIOUS CASTING-SANDS.

| | I. | II. | III. | IV. |
|--------------------|---------------|----------------|----------------|----------------|
| Silica | 92·083 | 91·907 | 92·913 | 90·625 |
| Oxide of iron..... | 2·498 | 2·177 | 1·249 | 2·708 |
| Alumina..... | 5·415 | 5·683 | 5·850 | 6·667 |
| Lime | traces | 0·415 | traces | traces |
| | <u>99·996</u> | <u>100·182</u> | <u>100·012</u> | <u>100·000</u> |

I. Sand from the foundry of Freund at Charlottenburg. II. Sand employed at Paris for bronzes. III. Sand from Manchester. IV. Sand from the establishment of Laguna near Stromberg.

According to Kampmann, a good sand for moulds may be artificially made from the following mixture:—

| | |
|---|----|
| Fine quartzose sand..... | 98 |
| Red English ochre | 2 |
| Aluminous earth as little calcareous as possible..... | 5 |

⁷ Ann. des Mines, s. 4, 1845, viii. 689.

In the Museum of Practical Geology is a very fine iron-casting, which was exhibited at the Paris Exhibition in 1855. It is a circular disc, 40 inches in diameter, and about $\frac{3}{8}$ of an inch in thickness, presenting an elegant pattern of perforated tracery-work; its surface is remarkably smooth, and the impression sharp and even: it was produced at the works of Count Stolberg-Wernigerode, at Ilsenberg, in the Harz Mountains. The sand, which adhered to the surface of the casting as it came from the mould, was purposely left there; and the analysis of a portion of it, made in my laboratory by J. Spiller, gave the following results:—

COMPOSITION OF MIXTURE USED FOR CASTING-MOULDS AT ILSENBERG.

| | |
|---------------------------|--------------|
| Silica | 79.02 |
| Alumina..... | 13.72 |
| Protoxide of iron | 2.40 |
| Protoxide of copper | trace |
| Magnesia | 0.71 |
| Potash | 4.58 |
| | <hr/> 100.43 |

This sand is stated to consist of three different kinds of material, namely, common argillaceous sand, sand found in alluvial deposits, and sand from solid sandstone. As the first two contain clay, they are carefully heated to de-hydrate the clay. The sandstone is crushed under a hammer, and mixed with an equal weight of each of the other two kinds of sand. The mixture is ground by iron balls in a revolving drum, and afterwards passed through a flannel-lined cylinder, which moves up and down; it is thus obtained in the state of the finest flour, which in moulding may be made to receive the most delicate impression. The moulds used in making the so-called "lace-castings" of cast-iron are also prepared with this material, the patterns being formed of stamped and perforated paper.

A valuable casting-sand is obtained from the New Red Sandstone at Birmingham. There is a quarry of this sand at the old Cemetery in that town, the value of which, one of the Directors of the Company many years ago informed me, was estimated at not less than £20,000. Good casting-sand is obtained from the Woolwich beds, at Woolwich, and from the New Red Sandstone, occurring near Mansfield, Nottinghamshire. The latter sand, which is brownish-red, has been, I was informed some years ago, exported to Berlin for the moulds in which the delicate iron-castings, known as "Berlin castings," are made.

The Japanese show great skill in the art of casting metals in ornamental forms, and a specimen of a sand which they use for that purpose was brought to me by Mr. Fisher of Singapore. It had formed part of a core, and was, when I received it, in the state of coarse powder mixed with small pieces of charcoal. An analysis of it has been made in my laboratory by W. J. Ward, with the following results:—

COMPOSITION OF JAPANESE CASTING-SAND.

| | |
|------------------------------|-------|
| Silica | 67.60 |
| Alumina..... | 17.64 |
| Sesquioxide of iron | 1.60 |
| Protoxide of iron | 2.30 |
| Protoxide of manganese | 0.31 |
| Protoxide of copper..... | 0.11 |
| Oxide of zinc | 0.49 |
| Lime | 0.86 |
| Magnesia..... | 1.41 |
| Potash | 3.69 |
| Soda..... | 0.14 |
| Sulphuric acid..... | 0.09 |
| Chlorine..... | trace |
| Carbon | 1.76 |
| Water | 1.78 |
| | <hr/> |
| | 99.78 |

There are other refractory substances, besides those mentioned in the preceding pages, which are used by the metallurgist, such, for example, as gneiss and mica-schist; but as their application is only local, any remarks concerning them will be found in the sequel, in the descriptions of particular furnaces.

I have not considered it necessary to give any special description of silica, alumina, lime, and magnesia, as I assume that the reader is acquainted with their properties.

FUEL.

THE word "fuel" is used to denote substances which may be burned by means of atmospheric air, with sufficient rapidity to evolve heat capable of being applied to economical purposes. There are only two elements which are thus applied, namely, carbon and hydrogen. All fuel consists either of vegetable matter, or of the products of the natural or artificial decomposition of that matter. Vegetable matter, which chiefly consists of woody tissue, may *practically* be regarded as composed of carbon, hydrogen, and oxygen, together with a small quantity of so-called earthy matter. The former constitute the *organic*, and the latter the *inorganic*, part of vegetable matter. The original sources of the organic part are water and, except in particular cases, the carbonic acid of the atmosphere, both of which are decomposed in the economy of plants by the action of solar light. The sun, therefore, is really the source of the heat-producing power of fuel.¹

From the preceding considerations it will appear, that the hydrogen in fuel must always be in association with carbon; but the converse is not true, for carbon, *practically* free from hydrogen, may be procured abundantly and applied as fuel. Thus the combustible part of anthracite, of well-burnt charcoal, or of coke, consists essentially of carbon and a small proportion of hydrogen, which may, so far as concerns useful effect, be neglected. In all fuel containing carbon, hydrogen, and oxygen, the proportion of hydrogen may be equal to, or greater, but *never less* than, that required to form water with the oxygen.

It may be shown that it is only the hydrogen in *excess* which is available as a source of heat, so that in the combustion of a substance, of which the composition may be represented by carbon

¹ Berthelot has suggested the possibility of the formation of bituminous matters, such as pitch and petroleum, from carbonic acid, without the agency of vegetation, by heating alkaline metals in an atmosphere of steam and carbonic acid gas. The gaseous hydro-carbon, named acetylene, C^2H^2 [C^2H^2], would be produced, with the formation of acetylides of those metals. Now, assuming, as Davy did, the existence of alkaline metals in a free state, in the interior of the earth, Berthelot supposes that carbonic acid might, in filtering through the crust of the earth, come in contact with those metals and produce acetylides of them, which by the action of the vapour of water would evolve free acety-

lene. But as this substance would not be able to continue to exist under those conditions, it would be replaced by the products of its decomposition, namely, bitumens, pitch, petroleum, etc., in which case those natural carbides would have a purely mineral origin. The presence of carbides in matters ejected from volcanoes and in meteorites may be adduced in favour of Berthelot's hypothesis. It is, however, certain that coal and other solid combustible minerals, properly so designated, are of organic origin; and there is no geological evidence of the existence of bituminous matters, at least not in sensible quantity, before the appearance of plant-life upon the earth. (Ann. des Mines, s. 6, 1867, xii. 644.)

and water, the carbon alone is the source of heat, inasmuch as the hydrogen may be regarded as *virtually* existing in combination with oxygen in the state of water, and the carbon cannot be burned without the evaporation of this water at the expense of the heat developed by its own combustion. It is true that the hydrogen may perform an important function in such a fuel in generating *flame*, but the proposition is, nevertheless, true that that part of it which may be regarded as existing in combination with oxygen in the state of water, not only does not contribute to the *actual amount* of heat produced, but consumes, so to speak, no inconsiderable portion of it.

The Germans apply the word *disposable* to that part of the hydrogen which is in excess of what is required to form water with the oxygen present; and as the word is convenient, it will be used in the sequel in that sense: the word *non-disposable* will also be used to indicate the other part, which, so far as relates to heat-producing power, may be regarded as *virtually* existing in combination with oxygen in the state of water.

The products of the perfect combustion of carbon and hydrogen, either in oxygen or in atmospheric air, are carbonic acid and water, respectively. The same products result from the perfect combustion by oxygen of any compound of carbon and hydrogen, or of these elements associated with oxygen. The amount of heat which any element in the same allotropic condition develops on perfect combustion is perfectly definite and constant, and is the same whether combustion be *slowly* or *rapidly* effected; it is as definite as the amount of electricity evolved in the voltaic battery by the oxidation of a metal, like zinc, for example. It has been ascertained that the amount of heat produced by the perfect combustion of carbon and sulphur varies in a small, though very sensible, degree with their allotropic condition. The term *perfect*, which has been used to qualify the degree of oxidation or combustion of carbon and hydrogen, requires explanation. In respect to carbon, it expresses the *maximum* of oxygen with which it is capable of combining, but in respect to hydrogen it does not, for oxygenated water, or peroxide of hydrogen, contains twice as much oxygen as water. Yet in respect to each of those elements, it indicates the product of oxidation of the highest degree of *stability*, the affinity by which the second atom of oxygen is held in combination in oxygenated water being extremely feeble.

The *calorific intensity*, or pyrometric effect of heat, must not be confounded with the *quantity* of heat developed in combustion. The quantity of heat generated by the perfect combustion of a body, A, may be much greater than that of another body, B, weight for weight, but the intensity of the heat derived from B may far exceed that from A. However, the intensity of the heat developed on the combustion of the *same* body will, *cæteris paribus*, be proportionate to the *rapidity* of combustion; or, in other words, it will be inversely as the time in which combustion is effected. The term *calorific intensity* will be employed in contradistinction to *calorific power*, which expresses the *relative* quantity of heat.

When a piece of well-burnt dry charcoal is ignited and exposed freely to the air, it burns without sensible flame, and the product is carbonic acid. When, on the other hand, a piece of light dry wood is ignited, it burns with much flame, and the products, if the combustion be perfect, are carbonic acid and water. Ordinary flame is gas or vapour, of which the *surface*, in contact with atmospheric air, is burning with the emission of light. The truth of this proposition may be easily demonstrated by experiment upon the flame of a candle or gas-jet, as is stated in every treatise on chemistry. There is no sensible intermixture of the gas and its supporter of combustion, for in that case there would be an explosion, attended only with the instantaneous production of flame. The piece of charcoal contains nothing from which inflammable gas can be produced in sensible quantity by the application of heat, and the solid carbon, in combustion, passes directly to the state of carbonic acid. Hence, there can be no flame. But, when a piece of wood is ignited, the case is different. The inner substance of the wood, immediately below its burning surface, is precisely in the condition of wood which is heated in a close vessel, and evolves various inflammable volatile matters, of which some are permanently gaseous and others condensable into liquids. Hence, there must be flame. However numerous these products may be, it should be remembered, that, so long as they are ultimately converted into carbonic acid and water, the proposition, previously announced, respecting the quantity of heat developed is correct. When a piece of charcoal smoulders away in atmospheric air, or when it is burnt in oxygen gas, light is evolved. In the former case the light is only dull red, while in the latter it is intensely brilliant, yet without sensible flame.

It has been stated, that, when a single *piece* of charcoal is ignited and exposed to the atmosphere, it burns without flame, but the result may be different when charcoal is burned in *mass*, as in a furnace. In this case flame may be copiously produced by the combustion of carbonic oxide, which is generated when carbonic acid comes in contact with charcoal heated to bright redness; and this condition always occurs in a furnace which contains charcoal to the depth even of a few inches. When atmospheric air impinges upon incandescent charcoal, carbonic acid is formed, but as this gas rises through the overlying mass of charcoal heated to bright redness, it is converted, in greater or less degree, into carbonic oxide, which, afterwards coming in contact with atmospheric air, burns with its beautiful and characteristic blue flame: The same is also true of any kind of solid carbonaceous fuel, such as coke or anthracite.

The luminosity of flame is generally admitted to be caused by the presence of particles of *solid* matter within, or in immediate contact with, the gas in active combustion. In the flame of a candle or jet of coal-gas this matter is either wholly or chiefly carbon in a fine state of division, the existence of which may be shown by holding a cold glass rod for a second or two across the flame, when the portion within the burning surface will be covered with a black soot-like

deposit. The flame of a candle or of gas burning in atmospheric air is highly luminous, whereas that developed by the combustion of hydrogen by oxygen, in which case no solid particles, in the ordinary sense of that term, are present, is very feebly so; yet the intensity of the heat of the former is very small as compared with that of the latter. The luminosity, therefore, of flame affords no certain indication of its temperature. But when the flame resulting from the combustion of hydrogen and oxygen in admixture, in the proportion in which they exist in water, is projected upon a piece of lime, an intensely brilliant light is produced; and, under these conditions, there is a correspondence in intensity between the light and heat developed.

Frankland questions the truth of the generally received opinion above given concerning the luminosity of flame, and maintains that highly luminous flames may be produced which contain no solid particles, in the usual sense of that term;² for, accepting the atomic constitution of matter, solid particles, in the sense of atoms, are present in the most attenuated gas as well as in the densest kind of matter. The black substance which is deposited on the glass rod held across the flame of a candle or jet of coal-gas is, according to Frankland, a hydro-carbon compound, not pure carbon; but this seems irrelevant to the issue, because, whatever it may be, it is certainly for the most part fixed, not volatile. This chemist asserts that the luminosity of flame is proportionate to the density of the gas or vapour undergoing combustion, and to the temperature which is thereby developed.³ Thus he explains the diminished luminosity of the flame of a candle at high altitudes by the decrease in the density of the air as well as of the hydro-carbon vapour of the flame, and the great increase in luminosity under the opposite condition, as when a jet of hydrogen gas is made to burn in oxygen or atmospheric air greatly compressed. Tyndall contends, on the contrary, that the decrease in luminosity at great elevations is to be mainly ascribed to the greater mobility of the air. The particles of oxygen, he supposes in the case mentioned, penetrate the flame with comparative freedom, and so destroy its light, making atonement for the smallness of their number by the promptness of their action. By reducing the density of atmospheric air to one-half, he found the mobility of its atoms to be nearly doubled. It should be added that Tyndall and Frankland together have made observations on the combustion of stearine candles at the summit of Mont Blanc, and found the energy of combustion, notwithstanding diminished luminosity, to be the same as at Chamouni; for the quantity of stearine consumed in a given time was almost precisely the same at both altitudes.⁴ Now, if increased mobility of the air be caused by

² Lectures on Coal Gas, delivered in March 1867, at the Royal Institution of Great Britain, by Dr. Frankland, F.R.S. etc. Reprinted from the Journal of Gas Lighting, Water Supply, and Sanitary Im-

provement; London, 1867. (A pamphlet.)

³ Quart. Journ. of the Chem. Soc. 1862, xv. 168.

⁴ Heat considered as a Mode of Motion, by John Tyndall, F.R.S. etc., 1863, p. 50.

rarefaction, the opposite should result from compression, in which case the movement of the particles would become sluggish, intermixture of the air and flame-producing gas would be less rapid, and the diffusion of the gaseous products of combustion in the surrounding air would be retarded, with consequent increase of temperature.

As the temperature of the gaseous products of combustion under ordinary circumstances is much higher — and their density, consequently, much lower — than that of the surrounding atmosphere, flame will necessarily tend to rise. The length of flame will depend on the rapidity with which the combustible gas is generated, and the velocity with which flame rises will be proportionate, *cæteris paribus*, to the difference between the temperature of the gas in combustion and that of the surrounding atmosphere.

ON THE CALORIFIC POWER OF FUEL.

Formerly heat, or, as it was termed, caloric, in order to distinguish it from the sensation which it causes, was considered to be an imponderable all-pervading fluid, which might be added to, or subtracted from, ponderable matter, without causing increase or decrease of weight; and although the absolute quantity of heat in matter was unknown, yet its relative proportions could be found by experiment and numerically expressed. That theory of heat has been abandoned and replaced by what is designated the *dynamical* or *mechanical* theory, according to which heat is the result of motion amongst the atoms of matter, or, as it may be otherwise stated, of inter-atomic movement; and this motion is capable of being propagated through space from one body to another by undulations of a so-called ether, assumed to be everywhere existent in the universe. The relative effect of such heat-producing motion, or, in other words, the relative proportions of heat required to cause given effects, may be accurately indicated by numbers, just as if heat were a ponderable agent; and it is usual to speak of heat as if it were an independent material substance. Thus heat is said to be evolved or emitted, radiated, conducted, absorbed, and stored up or accumulated.

It follows from this theory, that the theoretical maximum degree of cold, or *absolute zero*, implies perfect quiescence both of the ether and the atoms of matter, a condition which in metaphorical language might be appropriately described as the death of matter.

Although, as previously stated, there is no means of estimating the *absolute* quantity of heat evolved by the combustion of a body, yet the *relative* quantities of heat evolved by the combustion of different bodies may be accurately determined. Rumford estimated the calorific power of a body by the number of parts by weight of water which one part by weight of the body would, on perfect combustion, raise one degree in temperature. Thus, assuming the specific heat of water to be the same at all temperatures, and that

there is no conversion of water into steam, 1 part by weight of charcoal, in combining with $2\frac{3}{4}$ parts by weight of oxygen to form carbonic acid, will evolve heat sufficient to raise the temperature of 8080 parts by weight of water 1° C. Similarly, 1 part by weight of hydrogen in combining with 8 parts by weight of oxygen to form water will raise 34,462 parts by weight of water 1° C. The relative calorific powers, therefore, of carbon and hydrogen are in round numbers as 8 : 34. = 4.25

UNIT OF HEAT.—The quantity of heat required to raise 1 gramme (15.432 grains) of water from 0° to 1° C. is conventionally taken as the *unit of heat* or *thermal unit*, or *calorie* of the French.⁶ It is not a matter of indifference which portion of the thermometric scale be selected, because near the boiling-point a greater quantity of heat is required to increase the temperature of water 1° than at lower temperatures.

DETERMINATION OF THE CALORIFIC POWER OF VARIOUS SUBSTANCES.

The calorific power of various bodies has been investigated by Rumford, Lavoisier, Dulong, Despretz, and Grassi; but we are indebted to Favre and Silbermann,⁶ and to Andrews,⁷ for the most trustworthy researches on the subject.

RUMFORD'S CALORIMETER.

Rumford employed in his experiments a rectangular vessel of thin sheet-copper containing a worm of three horizontal coils of the same metal. The vessel was 8 inches long, $4\frac{1}{2}$ broad, and $4\frac{3}{4}$ deep. The worm consisted of a flat tube $\frac{1}{2}$ inch in depth and 1 in breadth. One end protruded through the top of the box, and the other was fitted to a circular hole in the bottom, 1 inch in diameter, and in this hole was inserted a funnel, of which the mouth was $1\frac{1}{2}$ inch wide. The lower end of the worm was situated near one of the short sides of the vessel, and the other end issued vertically near the opposite side. There was an opening in the top of the box, through which could be introduced a thermometer, having a cylindrical bulb in length equal to the depth of the vessel, so that the mean temperature of the water could be ascertained. The substance, of which the calorific power was required, was burnt under, and within, the funnel, when a current of air circulated upwards through the worm, and escaped at the opposite end. The heated gaseous products of combustion thus conveyed the heat which was developed, through the worm, from which it was communicated to the surrounding water. In order to counteract the error arising from loss by radiation, the temperature of the water in the vessel was reduced, just before the com-

⁶ As English writers on this subject usually employ the French gramme for the unit of weight, I have followed their example. It is quite immaterial what unit is selected.

⁶ Ann. de Chim. et de Phys. s. 3, 1852, xxxiv. 357; 1852, xxxvi. 5; 1853, xxxvii. 406.

⁷ Phil. Mag. 1848, xxxii. 321, 426.

mencement of an experiment, a few degrees—say 5—*below* that of the surrounding atmosphere, and the combustion was continued until the temperature of the water was exactly 5 degrees *above* that of the atmosphere. By this arrangement it was estimated that the vessel would receive as much heat as it would lose, by radiation and conduction during the experiment. With a view to diminish the effect of conduction as much as practicable, the vessel was supported on pillars of wood. In order to test the power of the instrument to extract the whole of the heat from the gaseous products of combustion, they were, on their escape from the first, made to pass through a second similar vessel, when it was found that the temperature of the water in the second vessel was not increased.^s

The data required in the use of this instrument, or *calorimeter*, are as follow :—

The weight of the substance consumed (n).

The weight of the water (w).

The weight of the copper forming the vessel (c) and the specific heat of copper (s).

The initial temperature of the water, or that at the beginning of an experiment (t).

The final temperature of the water, or that at the close of an experiment (t').

By multiplying the weight of the copper used in the instrument by the specific heat of copper, the weight of water is found, which, in respect to absorption of heat, would be exactly equivalent to the weight of copper in the instrument.

Corrections for the specific heat of the glass of the thermometer, etc., would be necessary in experiments of great precision, but with Rumford's apparatus, which is comparatively rude, they would be superfluous.

Let x represent the amount of heat produced by the combustion of 1 part by weight of any given body in atmospheric air; the following formula will then express the calorific power of the body :—

$$nx = (t' - t) \times (w + cs)$$

$$\therefore x = \frac{(t' - t) \times (w + cs)}{n}$$

For example—

Let $n = 10$ parts by weight.

$w = 8900$ ditto.

$c = 1000$ ditto.

$s = 0.09515$ (Regnault).

$t = 11^\circ \text{C.}$

$t' = 20^\circ \text{C.}$

Then—

$$x = \frac{(20 - 11) \times [8900 + (1000 \times 0.09515)]}{10} = 8095.$$

That is to say, 1 part by weight of the substance on perfect combustion

^s Encyclopædia Metropolitana, 1830. Mixed Sciences, 2nd Division. Article on Heat, p. 266.

in atmospheric air raises 8095 parts by weight of water 1° C., which is nearly the calorific power of wood-charcoal.

RESEARCHES OF FAVRE AND SILBERMANN.

The apparatus employed in these researches was founded on the same principle as that of Rumford's, but constructed so as to ensure far more accurate results. All necessary corrections in the calculations have been made, and every precaution seems to have been taken in conducting the experiments; and, in general, the results of these observers nearly agree with those of Andrews. Favre and Silbermann experimented on carbon in the different allotropic states of diamond, graphite, and charcoal. Andrews and they ascribe the discrepancy in the results of previous observers to ignorance of the fact, first announced by Dumas and Stas, that, during the combustion of carbon, even in oxygen gas, a certain amount of *carbonic oxide* is always produced; and when carbon is only oxidized to the degree of carbonic oxide, *much less* heat is evolved than when it is oxidized to the maximum, so as to form carbonic acid. As it was not found possible to prevent the formation of some carbonic oxide during the combustion of carbon, even under the most favourable conditions, the amount of carbonic oxide produced in each experiment was accurately determined. This was done by passing the products of combustion first through a solution of potash, which absorbed the carbonic acid, and afterwards through a tube containing black oxide of copper heated to redness. By this means the carbonic oxide was completely converted into carbonic acid, which was collected in a solution of potash and weighed. The total amount of carbon consumed may thus be found, as well as the relation between the carbonic acid and carbonic oxide produced.

CALORIFIC POWER OF WOOD-CHARCOAL.

Correction was made in the manner already described for the amount of carbonic oxide formed in each experiment. The charcoal operated on was freed from associated impurities by heating it to incipient redness in a current of chlorine, hydrogen, and nitrogen, successively; and different specimens, thus prepared, yielded the same amount of heat on combustion, provided they had been completely deprived of hydrogen. The same result was obtained when the prepared charcoal had been heated to the temperature of iron-assays during a long time. Special arrangements were adopted to determine the amount of hydrogen which might be present in the charcoal, and correction was made accordingly. From the mean of a considerable number of results, 8080 was deduced as the calorific power of carbon in the state in which it exists in purified wood-charcoal.

CALORIFIC POWER OF DIFFERENT VARIETIES OF CARBON.

There is no exact relation, as will appear from the following

table, between the calorific power and the specific heat of carbon in different allotropic states.

| | Calorific power. | Specific heat (Regnault). |
|----------------------------|------------------|---------------------------|
| Wood-charcoal | 8080 | 0·24150 |
| Carbon of gas-retorts..... | 8047·3 | 0·20360 |
| Artificial graphite..... | 7762·3 | 0·19702 |
| Native graphite | 7796·6 | 0·20187 |
| Diamond | 7770·1 | 0·14687 |

A singular fact was observed in respect to diamond, namely, the change effected in its calorific power by heating it to 400° C. or 500° C., and then allowing it to cool before burning it in oxygen gas. Thus, the calorific power, before the preliminary heating, was 7770·1, and, afterwards, 7878·7, the difference being 108·6.

Favre and Silberman make the remarkable statement that when carbon is converted into carbonic acid by combustion in protoxide of nitrogen, more heat is evolved than by its combustion in pure oxygen or in atmospheric air. Thus its calorific power by combustion in the former gas was found to be 11158, or 3078 in excess of 8080, its calorific power when burned in free oxygen. If this be correct, and oxygen and nitrogen could be directly combined so as to form protoxide of nitrogen, heat would be absorbed and rendered latent by the combination.

CALORIFIC POWER OF CARBONIC OXIDE.

To effect the perfect combustion of carbonic oxide, it was found necessary to adopt the plan of Dulong, and burn it in admixture with one-third of its volume of hydrogen. The relative proportion of the two gases was ascertained in each experiment by passing some of the gaseous mixture, in its course to the combustion-chamber of the calorimeter, over black oxide of copper heated to redness, and determining the weight of the carbonic acid and water thereby produced, as in the process of an ordinary organic analysis. From the mean of two experiments, 1 gramme of carbonic oxide was found to evolve 2402·7 (say 2403) units of heat by conversion into carbonic acid.

The amount, therefore, of carbonic oxide containing 1 gramme of carbon will evolve 5607 units of heat, by conversion into carbonic acid; for, since carbonic oxide contains $\frac{3}{4}$ of its weight of carbon, $2\frac{1}{4}$ grammes of carbonic oxide will contain 1 gramme of carbon, and $2403 \times 2\frac{1}{4} = 5607$. But 1 gramme of carbon, in passing to the state of carbonic acid, evolves 8080 units. Hence, 1 gramme of carbon, by conversion into carbonic oxide, will evolve $8080 - 5607 = 2473$ units. This is a very striking fact, that carbon should, on passing only to the state of carbonic oxide, evolve less than one-third of the amount of heat which it evolves on passing to the state of carbonic acid. The probable explanation is, that, when carbon combines with the first equivalent of oxygen to form carbonic oxide, heat is rendered latent by the passage of the carbon from the solid to the gaseous state. It was formerly asserted, that the heat developed by combustion is proportionate to the oxygen consumed; but, in the case

of carbon at least, this law is assuredly erroneous so far as *sensible* heat is concerned.

CALORIFIC POWER OF HYDROGEN.

From the mean of six determinations, which all closely agree, the calorific power of hydrogen was found to be 34462. The weight of hydrogen consumed in each experiment was deduced from the weight of water collected.

CALORIFIC POWER OF MARSH-GAS, C^2H^4 [CH^4].

The gas was made by heating baryta with crystallized acetate of soda. Its calorific power, by combustion in oxygen, was found to be 13063, as deduced from the mean of three determinations. The relation in weight between the carbon and hydrogen in this gas is as 3 : 1. If, therefore, its calorific power were the mean of that of its elements, the number expressing it would be

$$[(8080 \times 3) + 34462] \div 4 = 14678,$$

which is considerably more than that found by experiment.

CALORIFIC POWER OF OLEFIANT-GAS, C^4H^4 [C^2H^4].

From the mean of two determinations the number deduced was 11857·8. The relation in weight between the carbon and hydrogen in this gas is as 6 : 1. If, therefore, its calorific power were the mean of that of its elements, the number expressing it would be $[(8080 \times 6) + 34462] \div 7 = 11848\cdot8$, which is nearly the number found by experiment.

TABLE OF THE CALORIFIC POWER OF VARIOUS SUBSTANCES.

| One Gramme of each of the following Substances was burnt. | Supporter of Combustion. | Product of Combustion. | Number of Grammes of Water heated $1^{\circ}C$. | Name of Observer. |
|---|--------------------------|------------------------|--|-----------------------|
| Diamond..... | Oxygen | Carbonic acid... | 7770 | Favre and Silbermann. |
| Graphite, native | " | " | 7811·5 | " |
| " " another specimen..... | " | " | 7781·7 | " |
| " artificial from blast-furnaces | " | " | 7787·5 | " |
| " " another specimen | " | " | 7737·1 | " |
| Carbon of coal-gas retorts | " | " | 8047·3 | " |
| Charcoal from wood | " | " | 7237 | Lavoisier. |
| " " | " | " | 7167 | Dulong. |
| " " | " | " | 7912 | Despretz. |
| " " | " | " | 7714 | Grassi. |
| " " | " | " | 8080 | Favre and Silbermann. |
| " " | " | " | 7900 | Andrews. |
| " from sugar | " | " | 8039·8 | Favre and Silbermann. |
| " from wood | " | Carbonic oxide | 2473 | " |
| " " | " | " | 2227 | Andrews. |

TABLE OF THE CALORIFIC POWER OF VARIOUS SUBSTANCES—continued.

| One Gramme of each of the following Substances was burnt. | Supporter of Combustion. | Product of Combustion. | Number of Grammes of Water heated 1°C. | Name of Observer. |
|--|-------------------------------------|-----------------------------------|--|--------------------------|
| Charcoal from wood | { Protoxide of nitrogen } Oxygen | Carbonic acid and nitrogen } | 11158·2 | { Favre and Silbermann. |
| Carbonic oxide | | Carbonic acid... | 2402·7 | |
| Hydrogen gas | ,, | Water | 34462 | ,, |
| ,, ,, | | ,, | 33808 | Andrews. |
| ,, ,, | | ,, | 34743 | Dulong. |
| ,, ,, | | ,, | 34666 | Grassi. |
| ,, ,, | Chlorine | { Hydrochloric acid | 23788·3 | { Favre and Silbermann. |
| Marsh-gas | Oxygen | { Carbonic acid and water ... } | 13063 | |
| ,, | ,, | ,, | 13108 | Andrews. |
| Olefiant-gas | ,, | ,, | 11857·8 | { Favre and Silbermann. |
| ,, | ,, | ,, | 11942 | |
| Alcohol, anhydrous | ,, | ,, | 7183·6 | { Favre and Silbermann. |
| ,, ,, | ,, | ,, | 6850 | |
| Sulphur, native, in fine crystals, very pure ... } | ,, | Sulphurous acid | 2220·9 | { Favre and Silbermann. |
| ,, native, opaque | ,, | | 2249 | |
| ,, melted seven years previously | ,, | | 2216·8 | |
| ,, melted an hour after crystallization | ,, | | 2258·6 | |
| ,, in the soft state $\frac{1}{2}$ an hour after melting } | ,, | | 2253·2 | |
| ,, in the state of flowers } | ,, | | 2307 | |
| Bisulphide of carbon | ,, | { Carbonic and sulphurous acids } | 3400·5 | { Favre and Silbermann. |
| Silicon, amorphous* | ,, | Silica | 7830 | |
| ,, after fusion and crystallization* | ,, | ,, | 7540 | ,, |
| Boron, amorphous* | ,, | Boracic acid | 14420 | ,, |
| Phosphorus | ,, | Phosphoric acid | 5747 | Andrews. |
| Zinc | ,, | Oxide of zinc... | 1301 | ,, |
| Iron | ,, | Magnetic oxide? | 4134 | ,, — see erratum p. xiii |

Ditte has deduced the calorific power of certain metals by an indirect method, for a description of which see the Comptes rendus, 1870, lxx. 935; 1871, lxxii. 762. By this method, he has found the calorific power of zinc to be 1357·6 and that of magnesium to be 6130·5 thermal units.

BERTHIER'S PROCESS OF ESTIMATING THE CALORIFIC POWER OF FUEL.

In the erroneous belief that the amount of heat evolved by combustion is proportionate to the amount of oxygen consumed, Berthier proposed to determine the calorific power of fuel by burning it by the oxygen in protoxide of lead, and ascertaining the quantity of lead thereby reduced to the metallic state. When charcoal, for

* Determined by indirect methods. Comptes rendus, 1870, lxx. 188, 252.

example, is heated in admixture with a sufficient quantity of protoxide of lead, it is converted into carbonic acid at the expense of the oxygen of the protoxide, with the reduction of an equivalent proportion of lead. In respect to pure carbon, or matters containing carbon and *no other reducing agent*, this process might be employed with advantage, as it may be easily practised, and would yield correct results in the comparison of one carbonaceous matter with another. But when *disposable hydrogen* is present, it may lead to erroneous conclusions, as will clearly appear from the following considerations. Three parts by weight of carbon reduce the *same* quantity of protoxide of lead as one part by weight of hydrogen. But the calorific powers of carbon and hydrogen are, in round numbers, as 8 : 34. The calorific power, therefore, of 3 of carbon : 1 of hydrogen is as 24 : 34. Hence, the same weight of lead obtained by reduction would in the case of carbon indicate a calorific power of 24, and in that of hydrogen 34; so that the process is inapplicable to the determination of the calorific power of substances containing variable proportions of carbon and hydrogen.¹

Berthier thus describes his process.² Mix intimately 1 part by weight of the substance, in the finest state of division, with at least 20, but not more than 40, parts of litharge. Charcoal, coke, or coal may be readily pulverized; but in the case of wood the saw-dust produced by a fine saw or rasp must be employed. The mixture is put into a close-grained conical clay crucible, and covered with 20 or 30 times its weight of pure litharge. The crucible, which should not be more than half full, is covered, and then heated gradually until the litharge is melted and evolution of gas has ceased. At first the mixture softens and froths up. When the fusion is complete the crucible should be heated more strongly for about ten minutes, so that the reduced lead may thoroughly subside and collect into one button at the bottom. Care must be taken to prevent the reduction of any of the litharge by the gases of the furnace. The crucible, while hot, should be taken out of the fire and left to cool, and, when cold, it is broken, and the button of lead detached, cleaned, and weighed. If preferred, the melted contents of the crucible may be directly poured into a conical ingot-mould. The accuracy of the result should be tested by repetition.

Forchhammer recommends that a mixture of 3 parts by weight of litharge and 1 part of chloride of lead should be used instead of litharge only, as this mixture fuses at a much lower temperature than litharge, and does not corrode the crucible so much as that substance.³

¹ I have assumed, in these observations, that the calorific power of hydrogen, as it exists in fuel,—in combination and in the solid state,—is the same as that of free gaseous hydrogen. The correctness of this assumption will be considered in

the sequel, when comparing the calorific power of fuel theoretically deduced, with that found by experiment.

² *Traité des Essais*, i. 228.

³ *Berg- und hüttenmännische Zeitung*, 1846, v. 465.

ON THE CALORIFIC INTENSITY OF FUEL.

In a practical point of view calorific intensity means the highest temperature which fuel is capable of producing, when burnt by atmospheric air under the most favourable conditions. But there is also a hypothetical point of view from which the subject of calorific intensity may be considered; and to that the attention of the reader will now be directed. The first point to be considered is the possibility of deducing the highest temperature, which the combustion of a given substance may develop, from the calorific power of that substance.

CALORIFIC INTENSITY OF WOOD-CHARCOAL.

Suppose 1 gramme of carbon in the state of wood-charcoal, and $2\frac{3}{4}$ grammes of oxygen—that is, the exact proportion in which these elements combine to form carbonic acid—be brought together, both at 0° C., and combine; and suppose, further, that the whole of the heat evolved is expended in raising the temperature of the carbonic acid, and that the *pressure* to which this gas is subjected remains *constant*. Now, if the specific heat of carbonic acid (under constant pressure) were the same as that of water, the hypothetical temperature after combustion would be found by dividing the number, given as the calorific power of wood-charcoal, by the weight of the carbonic acid produced, namely, $1 + 2\frac{3}{4} = 3\frac{3}{4}$ grammes. But, as the specific heat of carbonic acid is not the same as that of water, it will be necessary to multiply $3\frac{3}{4}$ by the number expressing the specific heat of carbonic acid, in computing its temperature after combustion.

It must be borne in mind, that, in the case just considered, it was assumed, that the *pressure* of the carbonic acid *remained constant*; and, consequently, that, owing to increase of temperature, its *volume* is expanded. But if the *volume* had remained *constant*, the *pressure* of the carbonic acid would have greatly increased; and the heat absorbed in expanding would have become *sensible*, instead of remaining *latent*. Hence, if in the hypothetical computation of temperature, the carbonic acid produced by combustion is supposed not to be allowed to expand, as the temperature rises, the computation will give a much higher number than in the case first considered. In the following computations it will be assumed, that at all temperatures gaseous carbonic acid, steam, and nitrogen obey Boyle and Mariotte's law, and that the specific heat of each, under constant pressure, is the same at all temperatures.

I. Assuming, that by the combustion of carbon, in the particular state of wood-charcoal, by oxygen gas, only carbonic acid is produced,—that the heat developed is wholly expended in raising the temperature of the carbonic acid,—that the carbonic acid is allowed to expand under the ordinary atmospheric pressure, that is to say, remains under *constant pressure*,—and that, at all temperatures, the

specific heat of gaseous carbonic acid, under a given *constant pressure*, is the same,⁴—the hypothetical maximum temperature of the carbonic acid, resulting from the combustion, at 0° C., of wood-charcoal by the equivalent proportion of oxygen gas required, is thus deduced:—

Let T = the hypothetical maximum temperature;

p = the calorific power of wood-charcoal = 8080;

s = the specific heat of carbonic acid = 0.2164.

$$\begin{aligned} \text{Then,} \quad T &= \frac{p}{s \cdot 6} \\ &= \frac{8080}{3 \cdot 6 \times 0 \cdot 2164} = 10183^\circ \text{C.} \end{aligned}$$

Since the ratio between the weight of the substance burnt and that of the product of combustion is constant, T remains the same whatever the weight of substance burnt.

II. Assuming all the conditions stated in I., with one exception, namely, that the *volume*, instead of the *pressure*, remains constant, T will be greater than in I., in the ratio of 1 : 1.265; this being the ratio between the quantity of heat required to produce a given increase of temperature in gaseous carbonic acid, when the *volume* remains constant, and that required when the *pressure* remains constant. In this case, therefore,

$$T = 10183 \times 1 \cdot 265 = 12881^\circ \text{C.}$$

III. Let it now be supposed, that the combustion of wood-charcoal, at 0° C., is effected by atmospheric air,⁵ containing the exact quantity of oxygen required to form carbonic acid; the nitrogen present in this case is heated along with the carbonic acid produced, and the temperature will, consequently, be *pro tanto* lower. One part by weight of oxygen in atmospheric air is mixed with 3.35 parts by weight of nitrogen, so that the weight of nitrogen to be heated, in the conversion

⁴ The specific heat of liquid water being taken as equal to 1, then, according to Regnault, the specific heat of the following substances, under *constant pressure*, is as follows, assuming that the specific heat of gases is constant for all temperatures:—

| | |
|-----------------------|--------|
| Oxygen | 0.2182 |
| Nitrogen | 0.2440 |
| Air | 0.2377 |
| Hydrogen | 3.4046 |
| Carbonic oxide | 0.2479 |
| Carbonic acid | 0.2164 |
| Sulphurous acid | 0.1553 |
| Olefiant-gas | 0.3694 |

| | |
|-----------------------------|--------|
| Marsh-gas | 0.5929 |
| Steam (vapour of water) ... | 0.4805 |

That the specific heat of air is constant, has been experimentally demonstrated by Regnault from -30° C. to 200° C.; but as regards carbonic acid, this is not exactly the case for Regnault found its specific heat to be 0.18427 from -30° C. to + 10° C., 0.20246 from 10° C. to 100° C., and 0.21692 from 10° C. to 200° C. —Comptes rendus, 1853, xxxvi. 686; Mém. de l'Académie des Sci. 1862, xxvi. 298 and 327.

⁵ Assumed to consist wholly of oxygen and nitrogen.

of 1 part by weight of wood-charcoal into carbonic acid, in the case in question, is $3.35 \times 2.6 = 8.93$. Now,

Let s' = the specific heat of nitrogen = 0.244 .

$$\begin{aligned} \text{Then,} \quad T &= \frac{p}{3.6s + 8.93s'} \\ &= \frac{8080}{(3.6 \times 0.2164) + (8.93 \times 0.244)} = 2718^\circ \text{C.} \end{aligned}$$

IV. Making the correction for *constant volume*, as in II., we obtain

$$T = 2718 \times 1.265 = 3438^\circ \text{C.}$$

CALORIFIC INTENSITY OF CARBONIC OXIDE.

V. The hypothetical maximum temperature, resulting from the combustion of carbonic oxide, by oxygen gas, under the conditions stated in I., is as follows, 1 part by weight of carbonic oxide being converted into 1.57 parts by weight of carbonic acid:—

Let p' = the calorific power of carbonic oxide = 2403 .

$$\begin{aligned} \text{Then,} \quad T &= \frac{p'}{1.57s} \\ &= \frac{2403}{1.57 \times 0.2164} = 7073^\circ \text{C.} \end{aligned}$$

VI. Making the correction for *constant volume*, as in II., we obtain

$$T = 7073 \times 1.265 = 8947^\circ \text{C.}$$

It should be noticed, that when 2 volumes of carbonic oxide combine with 1 volume of oxygen, the 3 volumes are condensed into 2 volumes of carbonic acid. But in this purely hypothetical calculation, it has not been considered desirable to introduce the complication, which would be caused by taking this condensation into account.

VII. The hypothetical maximum temperature resulting from the combustion of carbonic oxide by atmospheric air, under the conditions stated in III., is found by the following formula, in which the number 1.91 is the weight of nitrogen associated in atmospheric air with the weight of oxygen required to convert 1 part by weight of carbonic oxide into carbonic acid:—

$$\begin{aligned} T &= \frac{p'}{1.57s + 1.91s'} \\ &= \frac{2403}{(1.57 \times 0.2164) + (1.91 \times 0.214)} = 2982^\circ \text{C.} \end{aligned}$$

VIII. Making the correction for *constant volume*, as in II., we obtain

$$T = 2982 \times 1.265 = 3772^\circ \text{C.}$$

CALORIFIC INTENSITY OF HYDROGEN.

IX. In ascertaining the *calorific power* of hydrogen, the water resulting from its combustion is at first in the state of vapour, but is immediately afterwards condensed, with the evolution of heat, the *latent* heat of steam. This *latent* heat is imparted to the water in the calorimeter, and is, therefore, included in the number expressing the *calorific power* of hydrogen. It cannot, however, be concerned in the production of *temperature*, and, consequently, must be subtracted from the number expressing the calorific power found by experiment. In order to convert 1 part by weight of water at 100° C. into steam at 100° C., at the standard barometric pressure of 760 millimetres of mercury, there are required 537 thermal units.

A correction must also be made for the difference between the specific heat of water ($= 1$) and that of steam ($= 0.4805$), from 0° C. to 100° C., because in the computation of temperature the initial temperature is assumed to be 0° C. This difference is $(1 - 0.4805) \times 100 = 51.95$ thermal units, which must also be subtracted.

The sum of these two numbers is $537 + 51.95 = 588.95$, which is the number of thermal units to be deducted for one part by weight of steam produced; and since for 1 part by weight of hydrogen, 9 parts by weight of steam are produced, it is necessary to subtract $588.95 \times 9 = 5300.55$ from the number representing the calorific power of hydrogen found by experiment in the calorimeter. The number left by the subtraction, must then be divided by the number obtained by multiplying the weight of steam produced by the specific heat of steam, in order to ascertain the hypothetical maximum temperature, resulting from the combustion of hydrogen, by oxygen gas, under the conditions stated in I.

Let p'' = the calorific power of hydrogen = 34462;

s'' = the specific heat of steam = 0.4805.

$$\begin{aligned} \text{Then, } T &= \frac{p'' - \{[(1 - s'') \times 100] + 537\} \times 9}{9s''} \\ &= \frac{34462 - \{[(1 - 0.4805) \times 100] + 537\} \times 9}{9 \times 0.4805} \\ &= 6743^{\circ} \text{ C.} \end{aligned}$$

X. Making the correction for *constant volume* (the ratio between the specific heat of steam under constant pressure and under constant volume being as 1 : 1.302), we obtain

$$T = 6743 \times 1.302 = 8779^{\circ} \text{ C.}$$

The condensation which occurs, when hydrogen and oxygen combine, has not been taken into account, for the reason given under VI.

XI. The hypothetical maximum temperature resulting from the combustion of hydrogen by atmospheric air, under the conditions stated in III., is found by the following formula, in which the number 28.8 is the weight of nitrogen associated in atmospheric air

with the weight of oxygen required to convert 1 part by weight of hydrogen into steam.

$$\begin{aligned} T &= \frac{p'' - \{[(1 - s'') \times 100] + 537\} \times 9}{9s'' + 26 \cdot 8s'} \\ &= \frac{34462 - \{[(1 - 0 \cdot 4805) \times 100] + 537\} \times 9}{(9 \times 0 \cdot 4805) + (26 \cdot 8 \times 0 \cdot 244)} \\ &= 2684^\circ \text{C.} \end{aligned}$$

XII. Making the correction for *constant volume*, as in II., we obtain

$$T = 2684 \times 1 \cdot 302 = 3495^\circ \text{C.}$$

CALORIFIC POWER AND CALORIFIC INTENSITY CONSIDERED WITH REFERENCE TO FURNACE TEMPERATURES.

Let us assume, that the fuel used for heating a given furnace is wood-charcoal, that the sole product of combustion is carbonic acid, and that only such a quantity of atmospheric air at 0°C. is supplied as contains exactly sufficient oxygen for combustion. The maximum hypothetical temperature, resulting from the combustion of wood-charcoal by atmospheric air, is, as previously stated, 2718°C. , under *constant pressure*. Now the question arises, what number of thermal units will become available at lower temperatures—say, for example, 1500°C. —by the combustion of 1 part by weight of wood-charcoal, under the conditions above specified? Or, in other words, what number of thermal units will be available for useful application, after the carbonic acid produced and the nitrogen associated with it have been raised from 0°C. to 1500°C. ?

The answer is 3621 thermal units; for, as 4459 thermal units are required to raise the temperature of the carbonic acid and associated nitrogen from 0°C. to 1500°C. , by subtracting this number from 8080—the calorific power of wood-charcoal, *i. e.* the number of thermal units needed to raise 8080 grammes of water 1°C. —the number 3621 remains. The details of this computation are as follow:—

$$8080 - [(3 \cdot 6 \times 0 \cdot 2164) + (8 \cdot 98 \times 0 \cdot 244)] \times 1500 = 3621.$$

By the same method of computation as the preceding, we obtain 1194 thermal units as the number available in the case of carbonic oxide. Thus,—

$$2403 - [(1 \cdot 57 \times 0 \cdot 2164) + (1 \cdot 91 \times 0 \cdot 244)] \times 1500 = 1194.$$

By the same method of computation, we obtain 12866 thermal units as the number available in the case of hydrogen. Thus,—

$$34462 - \{[(0 \cdot 5195 \times 100) + 537]9 + [(9 \times 0 \cdot 4805) + (26 \cdot 8 \times 0 \cdot 244)]1500\} = 12866.$$

From these numbers it will be perceived, that, in combustion by atmospheric air, when a temperature of 1500°C. is attained, there is a far larger number of thermal units available, or, what is equivalent,

a much greater *useful effect*, in the case of hydrogen, than in the case either of wood-charcoal or carbonic oxide. At lower temperatures it will be found that the useful effect of hydrogen is *relatively greater still*.

On comparing the *calorific power* with the *calorific intensity* of wood-charcoal, of carbonic oxide, and of hydrogen, when burnt by *oxygen* gas, it should be noted, that the weight of the product (steam) of the combustion of hydrogen is much greater than that (carbonic acid) of the combustion of either wood-charcoal or carbonic oxide; and that, chiefly on this account, the temperature to which the steam produced is capable of being raised, by the very large amount of heat evolved on the combustion of hydrogen, is lower than that, to which the carbonic acid produced is capable of being raised, by the much smaller amount of heat developed by the combustion of either wood-charcoal or carbonic oxide.

But when combustion is effected, not by *oxygen* gas, but by *atmospheric air*, the nitrogen of the latter, as well as the product of combustion, has to be heated; and in this case the very high calorific power of hydrogen is so much in its favour, that the hypothetical maximum temperature deducible is nearly as high as in the case of wood-charcoal, though not so high as in the case of carbonic oxide, in which the weight of nitrogen to be heated is relatively very small. These considerations help to explain why hydrogen produces a greater *useful effect*, as a fuel, than wood-charcoal or carbonic oxide, notwithstanding its lesser *calorific intensity*.

But, whether in the combustion of fuel in actual practice by atmospheric air, the hypothetical maximum temperature can ever be attained, is doubtful. Heat must be lost by *radiation*. In air-furnaces, which are chambers having a grate at the bottom and a flue at the top, much heat is lost by radiation from the grate. In blast-furnaces, which are chambers closed at the bottom, with the exception of one or more small apertures through which air is blown in, the loss by radiation may be diminished by the absence of a grate. But as there is no building material which is a perfect non-conductor of heat, the temperature of the outer walls of furnaces may in the course of time rise high enough to cause considerable loss of heat by *radiation* and *conduction*. There must also be loss of heat from the gaseous current constantly flowing through the incandescent fuel, and finally escaping from the furnace at a temperature considerably higher than that of the atmosphere. The loss will be unnecessarily increased if *too much air* is allowed to pass through the fuel, because in that case heat will be expended in raising the temperature of the air in excess; and there is reason to believe that in many cases loss from this cause may be greater than is generally supposed.

Bessemer has proposed to construct furnaces in chambers in which the air might be artificially compressed, with a view to increase of temperature; and the reason of this proposal will, it is hoped, be understood from the foregoing considerations on calorific intensity. He imagined that by this means he could produce a temperature of 50,000° F.!

DISSOCIATION.—In the foregoing considerations on calorific intensity no account has been taken of the phenomenon of dissociation, which occurs at high temperatures, and which must interfere with the production of the hypothetical maximum temperatures given by the above computations.

By the term *dissociation*, the reader will bear in mind, is meant the severance of the chemical union between two or more elements, which takes place at high temperatures by the effect of heat alone. As examples of dissociation may be mentioned the resolution of carbonic acid into carbonic oxide and oxygen, at 1000° C. or 1200° C., and of water, into its elements, at 2500° C.⁶

PYROMETERS.

The term *pyrometer*, which was first suggested by Musschenbroek,¹ is applied to instruments used for measuring *high* temperatures, such as are produced in furnaces, while the term *thermometer* is restricted to instruments used for measuring *low* temperatures, say, below the boiling-point of mercury.

The requirements of a good pyrometer are as follow:—

I. Its indications should be constant for the same temperature, and not vary with repeated use, owing to gradual chemical or physical changes.

II. If it is to *measure degrees of temperature* (and not merely to indicate when the temperature required for any given operation is attained), its indications, at different temperatures, must be related to each other according to some known law.

III. If possible, different instruments should be so uniform in their indications, as not to require to be compared with, and graduated by each other, or a standard instrument, except where great accuracy is required.

A description of the numerous pyrometers which have been invented is not within the scope of this work, and it is, therefore, proposed in the following pages to state only the principles on which they have been constructed, except in one or two particular instances. It may here be premised that no satisfactory pyrometer has yet been constructed, which will compare with thermometers, in respect to facility of observation, and, probably also, accuracy of measurement. These principles may be thus classified:²—

⁶ *Leçons sur la dissociation*, by H. Sainte-Claire Deville, contained in a work entitled "*Leçons de Chimie*," by Berthelot and others, pp. 296 and 303. Paris, 1866.

¹ *Tentamina Experimentorum Naturalium*, etc., Leyden, 1731, pt. 2, p. 12.

² The classification which I have adopted is nearly the same as that given by

Weinholt in an article entitled "*Ueber die Messung hoher Temperaturen*," contained in the "*Programm der königlichen höhern Gewerbeschule, Baugewerkschule und Werkmeisterschule zu Chemnitz, Ostern (Easter) 1873*," pp. 2-42. For further information on the subject of pyrometers, see the various works referred to by Weinhold.

PRINCIPLES ON WHICH PYROMETERS HAVE BEEN CONSTRUCTED.

- I. Change in the Volume of Bodies . . . $\left\{ \begin{array}{l} \text{A. Contraction of a Solid Body.} \\ \text{B. Expansion of } \left\{ \begin{array}{l} 1. \text{ Solid Bodies.} \\ 2. \text{ Gases.} \end{array} \right. \end{array} \right.$
- II. Change in the Physical State of Bodies.
- III. Conduction of Heat by Solid Bodies.
- IV. Radiation of Heat.
- V. Production of Thermo-electric Currents.
- VI. Change in the Electrical Resistance of Conductors.
- VII. Calorimeter Methods.
- VIII. Dissociation of Chemical Compounds.

 ON THE PRACTICAL APPLICATION OF THE FOREGOING PRINCIPLES.

I.—A. CONTRACTION OF A SOLID BODY.

WEDGWOOD'S PYROMETER.

The only pyrometer constructed on this principle is that invented by Wedgwood, and first described by him in 1782. The substance used was china-clay, which, after complete dehydration, he found continued to shrink, permanently, the higher the temperature to which it was exposed. He assumed that the degree of shrinkage was *directly* proportional to the temperature, and, accordingly, deduced the latter from the former, which was easily ascertained, as will be shown in the following account of his method of procedure. The purest Cornish china-clay was first washed and dried, and then kneaded with about $\frac{2}{3}$ its weight of water. The paste so prepared was fashioned by means of moulds into small pieces of a uniform size, which were gradually dried, and raised to "a red-heat, fully visible in daylight." At first he used pieces in the form of rectangular prisms, but as these were found to contract unequally in different directions, a spherical form, with a flat surface in one part, was adopted. The diameter of these pieces, which henceforth will be termed *trial-pieces*, measured in a given direction, say parallel to the flat part, is the zero of the scale. Measurement is made by means of an instrument consisting of "two pieces of brass, 24 inches long, with the sides exactly straight, divided into inches and tenths, [which pieces are] fixed $\frac{1}{10}$ of an inch asunder at one end, and $\frac{3}{10}$ at the other, upon a brass plate." Thus a scale is formed, which is graduated into 240 degrees or tenths of inches, the zero being at the end where the two graduated pieces of brass are widest apart, and the 240th or highest degree being at the other end, where the distance between the two pieces of brass is $\frac{2}{3}$ less than that at the zero end. Hence, there is a decrease of $\frac{1}{240}$ of the distance at the zero end, for each successive degree. In order that the trial-pieces may fit the zero of the scale, they must measure exactly $\frac{1}{10}$ of an inch in the direction previously stated.

In making an experiment, a trial-piece is put into the furnace at the exact spot where it is desired to measure the temperature, and left until it is believed to have acquired the temperature of that spot, after which it is taken out, allowed to cool, and then measured. When there is reason to apprehend that the trial-piece might be acted on by corrosive matter within the furnace, it should be protected by enclosing it in a small vessel of "crucible clay." By way of example it may be stated that brass melted at 21° p. (p. = Wedgwood's pyrometer), silver at 28° p., and gold at 32° p. The highest temperature which Wedgwood was able to obtain in his experiments, namely 160° p., was produced in an air-furnace 8 inches square; but we are not informed what kind of fuel was used.

This kind of pyrometer may, doubtless, be serviceable to potters and others, for enabling them roughly to measure relative temperatures; but as an instrument of scientific precision, it is valueless. It is difficult to conceive how absolute identity should be secured in the physical characters of trial-pieces made from mixtures prepared at different times. Further, assuming that there is a relation between shrinkage and temperature, yet there is nothing to show that the former is *directly* proportional to the latter; and unless this can be shown, it is obvious that Wedgwood's pyrometer is useless as an instrument for measuring *absolute* temperatures—an objection which applies to nearly all pyrometers—however convenient it may be for approximately measuring *relative* temperatures. It may be added that mixtures of various kinds were tried by Wedgwood as substitutes for china-clay, but without removing either of the objections just urged against his pyrometer.³

B.—1. EXPANSION OF SOLID BODIES.

This principle has been applied by measuring the difference in the degree of expansion by heat of different substances. A metallic bar, inserted in a hollow cylinder made of a different metal, or of some other infusible material, has been used, and the difference of expansion registered, by causing the bar, in expanding, to move an index of infusible material, placed within the cylinder.

2. EXPANSION OF GASES.

The most common application of this principle is seen in the air-thermometer. A vessel of known capacity, made of infusible glass or other refractory material, and connected with a capillary tube open at the other end, is placed in a furnace, and the air within is allowed to expand; after which the tube is hermetically sealed at the open end. The apparatus is then withdrawn from the furnace and allowed to cool. After cooling, the sealed end of the tube is immersed in mercury,

³ For further information on Wedgwood's pyrometer, see Phil. Trans. 1782, lxxii. (pt. 2) 303; 1784, lxxiv. (pt. 2) 358; 1786, lxxvi. (pt. 2) 390; also Nat.

Philosophy (Library of Useful Knowledge), 1832, ii., the article entitled "The Thermometer and Pyrometer."

and then broken off, when the mercury enters the vessel. The residual air is passed into a graduated glass tube and measured; or the reduction in volume of the air may be computed from the weight of the mercury which has entered the apparatus. The temperature is deduced from Boyle and Mariotte's law, which states the relation between the volume of a gas and its temperature. In principle this kind of pyrometer is probably quite satisfactory, but hitherto no material suitable in every respect for the apparatus has been discovered. The so-called infusible glass is fusible at furnace temperatures; and at such temperatures porcelain vessels suffer a permanent change in capacity, while vessels of metal become porous.

II. CHANGE IN THE PHYSICAL STATE OF BODIES.

This principle has been applied by Prinsep, whose pyrometer has been previously described in this volume (see p. 83).

III. CONDUCTION OF HEAT BY SOLID BODIES.

This principle has been applied by introducing one end of an iron bar into a furnace, and inserting the bulb of a mercurial thermometer in a hole drilled in the other end of the bar; the rise of the mercury in the thermometer being regarded as proportional, *ceteris paribus*, to the temperature of the furnace. The method affords only comparative results.

IV. RADIATION OF HEAT.

This principle has been applied by allowing the heat radiated from a furnace, to pass through an orifice in a screen, and concentrating it, by a lens, upon the bulb of a thermometer, placed at a given distance from the furnace. This method affords only comparative results.

V. PRODUCTION OF THERMO-ELECTRIC CURRENTS.

This principle has been applied, either by placing a thermo-electric pile within a furnace itself; or by exposing it to the radiant heat of a furnace; or by introducing one end of a metal rod into a furnace, and placing the pile in contact with the other end for a given time. These methods afford only comparative results.

VI. CHANGE IN THE ELECTRICAL RESISTANCE OF CONDUCTORS.

C. W. SIEMENS' ELECTRICAL-RESISTANCE PYROMETER.

The principles, upon which the measurement of temperatures by means of this instrument depends, are: 1st, the increase which takes place in the resistance offered by a metallic conductor to the passage of an electric current, when the conductor is heated; 2ndly, the law, that when two branches, or conductors, are substituted for a single conductor in part of a circuit through which an electric current is passing, the intensities of the separate currents in the two branches will be inversely proportional to the resistance offered by each separate branch.

Siemens has conducted a series of experiments to determine the rate of increase in the resistance of a metallic conductor when heated, and believes himself justified in deducing a law which is expressed in the following formula :—

Let R = the resistance,
 T = the temperature, computed from the absolute zero ($-272^{\circ}85$ C.),
 α, β, γ = coefficients which vary for each metal.

Then,

$$R = \alpha \sqrt{T} + \beta T + \gamma.$$

Substituting the experimental values of α, β, γ in the case of platinum, the formula becomes :—

$$R = 0.039369 \sqrt{T} + 0.00216407 T - 0.24127.$$

Siemens has applied these principles by inserting a standard resistance coil in one branch of a circuit, through which an electric current is passed, and a coil of platinum wire, to be heated in a furnace, in the other branch. The relation between the intensities of the separate currents in the two branches, is measured by the relative quantities of water decomposed in two voltameter tubes, one of which is inserted in each branch. From these data, the resistance of the platinum coil is deduced, and, by comparing this with its known resistance at 0° C., with the help of the formula above given, the temperature of the furnace is computed.

The instrument will be better understood with the help of the following woodcuts, figs. 28, 29, and 30.⁴

B , the battery.

c , commutator for completing the circuit, and reversing the current. During each experiment, the current should be reversed at intervals of about half a minute, to prevent polarization of the electrodes in the voltameter tubes.

x, x' , the wires of the two branches leading to the two voltameter tubes.

L , three stout copper-wire conductors, of which one forms a part of the undivided circuit, and each of the others forms a part of one branch.

P , the portion of the three conductors, leading to the platinum coil, within the lower part of the wrought-iron tube, shown in fig. 29. Here platinum wires are substituted for copper, on account of the high temperatures to which this part of the tube is exposed. The platinum coil itself is wound round a small porcelain cylinder.

a , the standard resistance coil.

b, b' , binding screws connecting the battery wires with the commutator.

c , conductor forming a part of the undivided circuit.

⁴ The woodcuts are taken from drawings supplied to me by my friend Mr. Siemens.

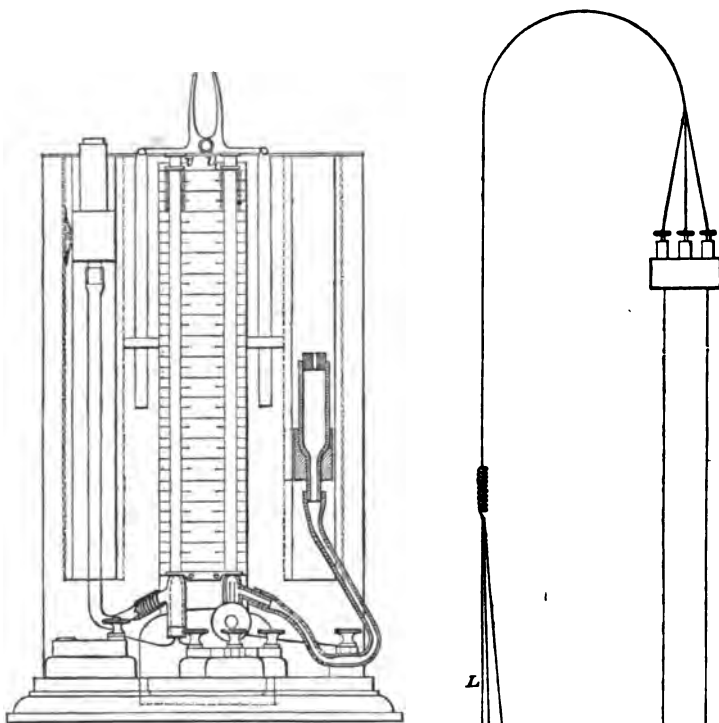
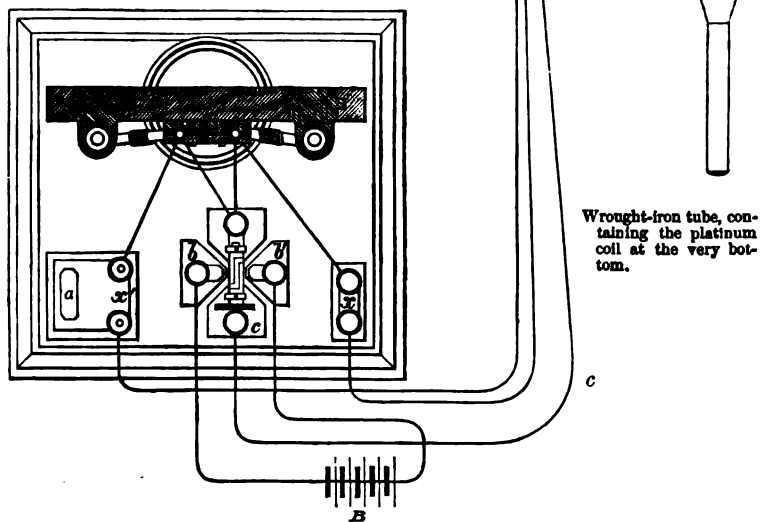


Fig. 28. Elevation of voltmeter and battery connections.



Wrought-iron tube, containing the platinum coil at the very bottom.

Fig. 29. Plan of voltmeter and battery connections.
C. W. Siemens' pyrometer.

v, v' , the two voltameter tubes, at the commencement of each experiment filled with acidulated water; in these the gases produced by the decomposition of the water collect; they are precisely similar to each other in form and dimensions, and are closed at the top by moveable india-rubber pads, which are pressed down air-tight, by means of weighted levers; graduated scales are fixed behind the voltameter tubes, and the pressure of the gases within them is reduced to the atmospheric pressure, by the aid of auxiliary tubes, with which they are connected by means of india-rubber tubing, and which slide up and down so that the water in the voltameter and auxiliary tubes, which are open to the atmosphere, may be adjusted to the same level.

x , the branch which contains the coil of platinum wire.

x' , the other branch, containing the standard resistance coil.

To use the instrument, the end of the wrought-iron tube is placed in the furnace, and, after sufficient time has elapsed, in the judgment of the experimenter, for the tube and platinum coil to acquire the temperature of the furnace, the battery circuit is completed, and the current allowed to pass until one of the voltameter tubes is about half full of gases; the current is then stopped, the gases evolved are reduced to the atmospheric pressure in the manner already explained, and the readings on the two scales are recorded.

It will be observed that, besides the resistances of the standard coil and of the platinum coil, in the two branches of the circuit, the resistance of the acidulated water and of the conductors which form parts of the two branches, are also included in the ratio between the total resistances of the two separate branches.

Now, the conducting wires which lead to the platinum coil become

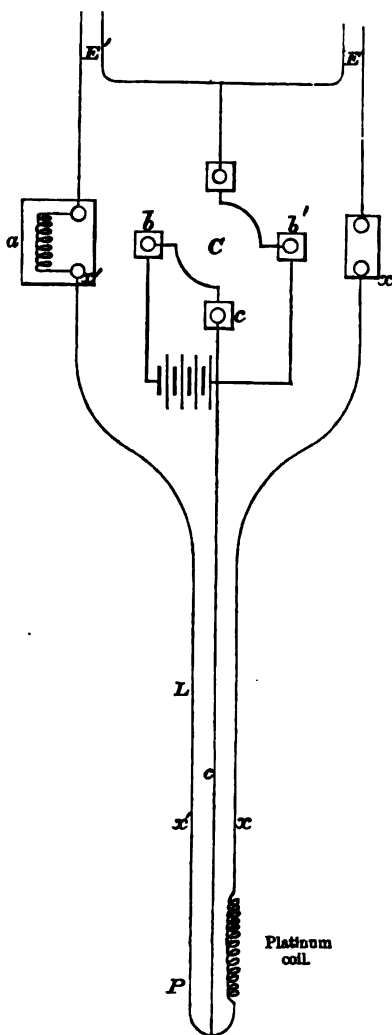


Fig. 30. Diagram of the circuit and branches.
C. W. Siemens' pyrometer.

heated, when the coil is heated, though in a less degree. The source of error thus introduced is diminished as far as possible by carrying the conducting wire of the undivided circuit down the wrought-iron tube, and dividing the circuit into branches close to the coil; so that the conducting wires of the two branches, both starting from the same point near the bottom of the tube, become equally heated. This arrangement obviates the difficulty so long as the total resistances in the two separate branches are equal; but, when this equality ceases, a correction requires to be made, the amount of which can hardly be determined *with precision*, as it will depend on the exact extent to which these conducting wires become heated in each particular experiment. Corrections are also required for the resistances offered by the other parts of the two branches and by the acidulated water, but these, it is believed, can be made with sufficient precision.

Siemens supplies a table with his instrument, for converting the voltameter readings into temperatures; and in preparing it, these and other less important sources of error have as far as possible been allowed for.

This instrument has been referred to a committee of the British Association for the Advancement of Science for investigation and report. In a preliminary report, presented at the Brighton meeting, held in 1872, it is stated that, "after being heated, it was found that the resistance of the pyrometer was slightly greater at a low temperature than it had been at the same temperature previously; but the permanent changes which thus took place became smaller and smaller after successive heatings; so that the instrument may be expected to reach a condition in which no further alteration will be produced in it by exposure to a red-heat."

It will be interesting to learn what the amount of this permanent change really is, and whether it interferes at all with Siemens' formula for finding the increase of temperature from the increase in the resistance. Mr. Siemens has informed me that he believes, that the small amount of variation, to which the pyrometer, as hitherto constructed, was found to be subject, may be considerably lessened, or altogether prevented, by thoroughly annealing the platinum coil, and enclosing it in a platinum tube; but we must await the results of further experiments before pronouncing a decided opinion upon its accuracy and fitness for the measurement of high temperatures.⁵

On these remarks, Mr. Siemens has made the following comment:—"In order to eliminate error from this source, it will be necessary to refer each coil from time to time to the original resistance at zero Centigrade, which is easily accomplished by taking a reading with the tube immersed in ice and water."

With regard to the *practical* application of his pyrometer, Mr.

⁵ Since the above was in type, Mr. Siemens has informed me, that so far as experiments have yet been made, there is every reason to hope that the alterations referred to in the text will prove successful.

Siemens has communicated to me, for publication, the following statements on his own authority:—"For ordinary temperatures, not exceeding the hot-blast, no change has ever been observed (Mr. Isaac Lowthian Bell has had some coils exposed for a long time without any change having taken place); whereas high temperature observations are practically the exceptions, requiring some precautions in the protection and occasional readjustment of the instrument."

With respect to Siemens' pyrometer, Weinhold, of Chemnitz, remarks, that, "of the pyrometers to be had ready-made, that of Siemens is the only kind which is serviceable and can be recommended."

VII. CALORIMETER METHODS.

The principle involved is the same as is used in the determination of specific heats, the method being simply reversed; the specific heat of the body, which communicates its heat to the surrounding water, or mercury, being known, its temperature is deduced from the number of thermal units communicated to the surrounding liquid.

Byström has invented a pyrometer, which he calls the hydro-pyrometer, on this principle. He heats a ball of platinum in a furnace, and causes it to roll quickly down an inclined clay tube, one end of which is inserted in the furnace, direct into a small water calorimeter. In order to prevent the ball from falling to the bottom of the vessel, it is made to drop into a cage of brass wire, the bottom of which is in the centre of the water.

This pyrometer is simple and convenient; and, by means of a table constructed by Byström, the temperature of the furnace may be immediately computed from observations on the temperature of the water before and after an experiment.

VIII. DISSOCIATION OF CHEMICAL COMPOUNDS.

It has been announced, that when carbonate of lime is heated in a closed vessel, exhausted of air, an atmosphere of carbonic acid, the density of which varies with the temperature, is formed by the decomposition of the carbonate; and that the increase in density, for increase of temperature, follows the same law as that of the tension of aqueous vapour at low temperatures.

The truth of this statement has been denied, but Lamy, relying upon it, has made use of the principle in constructing his pyrometer, which consists of a closed vessel, exhausted of air, but containing carbonate of lime, and with a manometer attached, to indicate the pressure of the gas within the vessel. The pressure, produced by the atmosphere of carbonic acid when the vessel is heated, is read off on the manometer, and the temperature calculated according to the above law; the pressure, which the carbonic acid exerts at two or three known temperatures, having been previously ascertained.

CLASSIFICATION OF FUELS.

WOOD.

PEAT.

| | | | | |
|-------------------------------|---|-----------------|---|-----------------------------|
| COAL | { | LIGNITE. | { | Non-caking, rich in oxygen. |
| | | BITUMINOUS COAL | | Caking. |
| | | ANTHRACITE. | | Non-caking, rich in carbon. |
| PRODUCTS OF CARBONIZATION. | { | SOLID | { | Wood-charcoal. |
| | | | | Peat-charcoal. |
| | | | | Coke. |
| | | VOLATILE | { | Carbonic oxide. |
| | | | | Hydrogen. |
| | | | | Hydro-carbons. |

WOOD.

Wood is essentially composed of *organic tissue* and a small proportion of *inorganic matter*; and, in its ordinary state, it contains a large quantity of water, which may be completely expelled at a temperature much below that at which the decomposition of the organic part would occur. This tissue is called *cellulose*, and has the same elementary composition in all kinds of wood, though it may be associated with widely different kinds of organic matter in different species of trees. Thus, fir-trees contain turpentine, and oaks tannin.

CELLULOSE.—The formula of organic tissue, or cellulose, in the pure state, is $C^{24}H^{20}O^{20}$ [$C^{12}H^{20}O^{10}$],¹ and its percentage composition is as follows:

COMPOSITION OF CELLULOSE.

| | |
|----------------|--------------|
| Carbon | 44.44 |
| Hydrogen | 6.17 |
| Oxygen | 49.39 |
| | <hr/> 100.00 |

The organic tissue is the only combustible part of wood of practical importance, as the associated organic matters are too small in quantity to deserve consideration.

In external characters there is great variation in different kinds of wood: some are light, soft, and loose in grain, while others are heavy, hard, and close in grain. They have, accordingly, been divided into

¹ Payen, Mémoires sur les Développements des Végétaux, p. 234. Paris, 1842.

two classes—light and soft woods, like pine, and heavy and hard woods, like oak. The inflammability of wood depends much upon its denseness and compactness, and, in a certain degree, also upon the presence of highly combustible matters, such as resin. Thus, every one is familiar with the difference in these respects between pine and oak.

KINDS OF WOOD EMPLOYED AS FUEL.

Wood is directly employed as fuel in metallurgical operations where high temperatures are not required; but as the heat, which wood, in its ordinary state, produces on combustion, is insufficient for many metallurgical operations, it is generally first converted into charcoal. The choice of wood intended for burning must depend upon the nature of the trees which grow in the vicinity of the smelting-works. In the following table is a list of the trees of which the wood is used as fuel in Europe:—

TABLE OF THE BOTANICAL, ENGLISH, FRENCH, AND GERMAN NAMES OF THE TREES USED AS FUEL IN EUROPE.

| Botanical Name. | English Name. | French Name. | German Name. |
|---|--|-------------------------------------|---------------------------------------|
| <i>Acer Pseudo-platanus</i> , L. ... | Sycamore | Sycomore | Ahorn. |
| <i>Betula alba</i> , L. | White birch | Bouleau | Birke. |
| <i>Alnus glutinosa</i> , Gaertn. ... | Alder | Aune | Erla. |
| <i>Carpinus Betulus</i> , L. | Hornbeam | Charme | Hainbuche. |
| <i>Fagus sylvatica</i> , L. | Beech | Hêtre | Buche. |
| <i>Fraxinus excelsior</i> , L. | Ash | Frêne | Esche. |
| <i>Populus tremula</i> , L. | Poplar or aspen | Tremble | Espe. |
| <i>Populus nigra</i> , L. | Black poplar ... | Peuplier noir ... | Schwarzpappel. |
| <i>Populus fastigiata</i> , Pers., regarded as a variety of <i>P. nigra</i> | Lombardy poplar | Peuplier d'Italie | { Italienische Pappel. |
| <i>Quercus Robur</i> , L. | Oak | Chêne | Eiche. |
| <i>Quercus Ilex</i> , L. | Evergreen oak .. | Yeuse | Steineiche. |
| <i>Tilia Europea</i> , L. | { Lime or linden-tree | Tilleul..... | Linde. |
| <i>Æsculus Hippocastanum</i> , L. | Horse-chestnut | Marronnier d'Inde | Rosakastanie. |
| <i>Salix alba</i> , L. | White willow... | Saule | Weisse Weide. |
| <i>Salix caprea</i> , L. | { Great round-leaved willow } | Saule Marceau | Saalweide. |
| <i>Ulmus campestris</i> , L. | Elm | Orme | Ulme. |
| <i>Abies excelsa</i> , D. C.; syn. } <i>Pinus Abies</i> , L. | Spruce fir | Faux sapin..... | { Edeltanne, Rothtanne, Schwarztanne. |
| <i>Abies pectinata</i> , D. C.; syn. } <i>Pinus Picea</i> , L. | Silver fir..... | Sapin commun | { Fichte, Weisstanne. |
| <i>Larix Europea</i> , D. C. | Larch | Melèze..... | Lärche. |
| <i>Pinus sylvestris</i> , L. | { Scotch fir, common pine, Norway or Riga pine or fir..... } | { Pin sauvage, pin de Genève..... } | Kiefer. |

In the south of Spain shrubs of various kinds and the refuse of the so-called Esparto grass (*Stipa tenacissima*) are used as fuel in lead-smelting.

COMPOSITION OF WOOD.

The following table has been compiled from the results of Chevandier.² In every case a sample was prepared for analysis by collecting and mixing the sawdust produced by sawing billets in two from the top, middle, and bottom of the trunk; so that the mixture represented the average composition of every part of the trunk, inclusive of bark and alburnum. The sawdust was dried at 140° C., and placed in a dry vacuum until it ceased to lose weight.

I. TABLE SHOWING THE PERCENTAGE COMPOSITION OF DRY WOOD.

| No. | Name of Tree. | Age and Part of Tree. | Ash per cent. | Composition exclusive of Ash. | | | | Mean Composition exclusive of Ash. | | | |
|-----|---------------|---|---------------|-------------------------------|----------|---------|-----------|------------------------------------|----------|---------|-----------|
| | | | | Carbon. | Hydrogen | Oxygen. | Nitrogen. | Carbon. | Hydrogen | Oxygen. | Nitrogen. |
| 1 | Beech | 70 years old | 0.86 | 49.89 | 6.13 | 43.09 | 0.88 | 49.94 | 6.08 | 43.02 | 0.93 |
| 2 | " | 58 " | 1.00 | 49.96 | 6.02 | 42.79 | 1.23 | | | | |
| 3 | " | 69 " | 0.88 | 49.75 | 6.04 | 43.09 | 1.12 | | | | |
| 4 | " | Branch-wood | 2.15 | 50.49 | 6.11 | 42.64 | 0.76 | | | | |
| 5 | " | Shoots..... | 1.29 | 49.62 | 6.12 | 43.58 | 0.67 | | | | |
| 6 | " | Faggots from young stems of 25 to 30 years old ... | 1.50 | 51.15 | 6.31 | 41.74 | 0.80 | 51.08 | 6.23 | 41.61 | 1.08 |
| 7 | " | Faggots from the branches of trees 70 to 80 years old | 1.94 | 51.24 | 6.15 | 41.35 | 1.26 | | | | |
| 8 | " | Faggots from the branches of a tree 120 years old ... | 1.71 | 51.06 | 6.22 | 41.75 | 0.97 | | | | |
| 9 | " | Faggots from the branches of a tree 120 years old ... | 1.93 | 50.88 | 6.25 | 41.60 | 1.27 | | | | |
| 10 | Oak ... | 120 years old | 2.43 | 50.97 | 6.02 | 41.96 | 1.05 | | | | |
| 11 | " | From the branches of No. 10 | 2.03 | 51.01 | 6.00 | 41.72 | 1.26 | 50.69 | 6.03 | 42.00 | 1.28 |
| 12 | " | From young shoots of No. 10 | 1.68 | 50.09 | 6.07 | 42.31 | 1.52 | | | | |
| 13 | " | Faggots from shoots 30 years old ... | 1.45 | 50.82 | 6.23 | 41.98 | 0.97 | | | | |
| 14 | " | Faggots from the branches of a tree 50 years old ... | 1.56 | 50.73 | Lost. | Lost. | 0.99 | | | | |
| 15 | " | Faggots from a tree 70 years old ... | 2.10 | 50.93 | 6.15 | 41.91 | 1.01 | | | | |
| 16 | " | Faggots from a tree 130 years old ... | 2.16 | 51.08 | 6.10 | 41.74 | 1.08 | 50.89 | 6.16 | 41.88 | 1.01 |

² Recherches sur la composition élémentaire des différents bois, et sur le rendement annuel d'un hectare de forêts. Par M. Eugène Chevandier. Ann. de Chim. et de Phys. s. 3, 1844, x. 129.

TABLE SHOWING THE PERCENTAGE COMPOSITION OF DRY WOOD—*continued*.

| No. | Name of Tree. | Age and Part of Tree. | Ash per cent. | Composition exclusive of Ash. | | | | Mean Composition exclusive of Ash. | | | |
|-----------|---------------|---|---------------|-------------------------------|----------|---------|-----------|------------------------------------|----------|---------|-----------|
| | | | | Carbon. | Hydrogen | Oxygen. | Nitrogen. | Carbon. | Hydrogen | Oxygen. | Nitrogen. |
| 17 | Birch | 60 years old | 0.71 | 50.59 | 6.21 | 42.16 | 1.03 | 50.61 | 6.23 | 42.02 | 1.12 |
| 18 | " | From the branches of No. 17 | 1.03 | 50.79 | 6.29 | 41.48 | 1.44 | | | | |
| 19 | " | From the young shoots of No. 17 ... | 0.60 | 50.48 | 6.20 | 42.43 | 0.89 | | | | |
| 20 | " | Faggots from shoots 30 years old ... | 1.16 | 52.21 | 6.36 | 40.24 | 1.19 | | | | |
| 21 | " | Faggots from shoots 35 years old ... | 1.54 | 51.61 | 6.32 | 40.95 | 1.12 | 51.93 | 6.31 | 40.69 | 1.07 |
| 22 | " | Faggots from the branches of trees 50 to 60 years old | 1.26 | 51.97 | 6.25 | 40.89 | 0.89 | | | | |
| 23 | Poplar, Aspen | Branches and stem of a tree 25 years old. Average | 1.86 | 50.31 | 6.31 | 42.39 | 0.98 | 51.93 | 6.31 | 40.69 | 1.07 |
| 24 | " | Faggots from the branches of stems 25 years old ... | 2.98 | 51.02 | 6.28 | 41.65 | 1.05 | | | | |
| 25 | Willow | From a shoot 20 years old | 3.67 | 51.75 | 6.19 | 41.08 | 0.98 | 51.93 | 6.31 | 40.69 | 1.07 |
| 26 | " | Faggots from branches of shoots 20 years old ... | 4.57 | 54.03 ^a | 6.56 | 37.93 | 1.48 | | | | |
| Mean..... | | | 1.772 | 51.225 | 6.238 | 41.427 | 1.098 | | | | |

The next table is compiled from the results of Petersen and Schödler,⁴ except Nos. 27, 29, 31, 33, 34, 40, 41, which were obtained by Heintz.⁵ The analyses of the former were made in Liebig's laboratory, under his own inspection. A minute but unimportant error exists in these analyses, arising from the presence of a little carbonic acid in the ashes: but at the most it cannot exceed 0.2 per cent. Every specimen of wood analysed was taken from the trunk.

^a The proportion of carbon here given is considerably greater than what appears in the other analysis of willow-wood by Chevandier, and about 5% greater than that stated in the analysis of a willow in the following table. It is probably erroneous.

⁴ Ueber den absoluten Werth der gebräuchlichsten Holzarten als Brennmaterial; von Petersen und Schödler. Ann. der Pharm. 1836, xvii. 139.

⁵ Brix, Untersuchungen über die Heizkraft der wichtigeren Brennstoffe des Preussischen Staates, p. 44. Berlin, 1853.

II. TABLE SHOWING THE PERCENTAGE COMPOSITION OF DRY WOOD.

| No. | Name of Tree. | Composition exclusive of Ash. | | | Ash per cent. |
|-----|---|-------------------------------|-----------|--------------------------------------|------------------|
| | | Carbon. | Hydrogen. | Oxygen, inclusive of Nitrogen. | |
| 27 | Oak (var. <i>pedunculata</i>) | 49.95 | 6.06 | 43.99 | 2.03 |
| 28 | Oak | 49.43 | 6.07 | 44.50 | .. |
| 29 | Beech | 48.56 | 6.03 | 45.41 | 0.57 |
| 30a | ,, red | 48.18 | 6.28 | 45.54 | .. |
| 30b | ,, white | 48.53 | 6.30 | 45.17 | .. |
| 31 | Birch | 49.37 | 6.25 | 44.38 | 0.99 |
| 32 | ,, | 48.60 | 6.37 | 45.03 | .. |
| 33 | Hornbeam | 48.50 | 6.17 | 45.33 | 0.87 |
| 34 | Alder | 48.96 | 5.98 | 45.06 | 0.68 |
| 35 | ,, | 49.20 | 6.22 | 44.58 | .. |
| 36 | Ash | 40.36 | 6.07 | 44.57 | .. |
| 37 | Horse-chestnut | 49.08 | 6.71 | 44.21 | .. |
| 38 | Black poplar | 49.70 | 6.31 | 43.99 | .. |
| 39 | Lime | 49.41 | 6.86 | 43.73 | .. |
| 40 | Scotch fir, old wood | 50.18 | 6.12 | 43.70 | 0.63 |
| 41 | ,, young wood | 50.88 | 6.30 | 42.82 | 0.53 |
| 42 | ,, | 49.94 | 6.25 | 43.81 | .. |
| 43 | Spruce fir | 49.95 | 6.41 | 43.64 | .. |
| 44 | Silver fir | 49.59 | 6.38 | 44.03 | .. |
| 45 | Larch | 50.11 | 6.31 | 43.58 | .. |
| 46 | Apple | 48.90 | 6.27 | 44.83 | .. |
| 47 | Box (<i>Buxus sempervirens</i> , L.) | 49.37 | 6.52 | 44.11 | .. |
| 48 | Walnut (<i>Juglans regia</i> , L.) | 49.11 | 6.44 | 44.45 | .. |
| 49 | Plum (<i>Prunus domesticus</i> , L.) | 49.31 | 5.96 | 44.73 | .. |
| 50 | Cherry (<i>Prunus Cerasus</i> , L.) | 48.82 | 6.28 | 44.90 | .. |
| 51 | Pear (<i>Pyrus communis</i> , L.) | 49.40 | 6.35 | 44.25 | .. |
| 52 | Ebony (<i>Diospyrus Ebenum</i> , Retz) ... | 49.84 | 5.35 | 44.81 | .. |
| 53 | Cork-barked elm (<i>Ulmus suberosa</i> , Ehrh.) | 50.19 | 6.42 | 43.39 | .. |
| 54 | Locust-tree or acacia (<i>Robinia pseudo- acacia</i> , L.) | 48.67 | 6.27 | 45.06 | .. |
| 55 | Crack-willow (<i>Salix fragilis</i> , L.) | 48.84 | 6.36 | 44.80 | .. |
| 56 | Small-leaved maple (<i>Acer campestre</i> , L.) | 49.80 | 6.30 | 43.90 | .. |
| | Mean | 49.34 | 6.25 | 44.39 | .. |

The quantity of hydrogen, in excess of what is required to form water with the oxygen, is in the mean composition of the first table 1.06, and in the second table 0.70. But in the first table the proportion of oxygen given is exclusive of nitrogen, whilst in the second the nitrogen is included in the oxygen.

COMPOSITION OF DECAYED WOOD.—The following analysis, made in my laboratory by W. J. Ward, of a specimen of decayed oak-wood is presented here for the sake of comparison with the foregoing analyses of different kinds of wood. The large proportion of ash is doubtless due to the gradual removal of the organic constituents during decay.

| Constituents per cent. of Decayed Oak Wood. | Inclusive of Ash and Water. | Exclusive of Ash and Water. |
|---|-----------------------------|-----------------------------|
| Carbon | 43·59 | 51·17 |
| Hydrogen | 4·82 | 5·66 |
| Oxygen and nitrogen | 36·78 | 43·17 |
| Ash | 5·12 | — |
| Water | 9·69 | — |
| Total | 100·00 | 100·00 |

PROPORTION OF ASHES YIELDED BY WOOD.

This subject has been investigated by many observers, and by no one in a more complete and satisfactory manner than by Chevandier, to whom we owe the following average results of no less than 524 incinerations: ⁶—

| Name of the Wood. | Number of Incinerations. | Mean Percentage of Ashes. |
|-----------------------------------|--------------------------|---------------------------|
| Willow | 17 | 2·00 |
| Aspen | 59 | 1·73 |
| Oak | 93 | 1·65 |
| Hornbeam | 73 | 1·62 |
| Alder | 26 | 1·38 |
| Beech | 93 | 1·06 |
| Scotch fir (<i>pin</i>) | 28 | 1·04 |
| Silver fir (<i>sapin</i>) | 46 | 1·02 |
| Birch | 89 | 0·85 |

The average percentage of ashes from different parts of these woods is as follows:—

| Portion of the Tree. | Percentage of Ashes. |
|--|----------------------|
| Entire wood of young shoots ⁷ | 1·23 |
| Wood split into billets ⁸ | 1·34 |
| Entire wood of branches | 1·54 |
| Faggots of twigs | 2·27 |

Although the *geological* character of the ground does not appear to exert any sensible influence on the proportion of ashes, at least in the case of hard woods, yet the observations of Chevandier indicate that the proportion is affected by the physical properties of the ground, such as porosity, etc., and by the character of the waters which moisten the roots.⁹ Wood from different parts of an old tree contains a variable proportion of ashes: the trunk contains the least, and the small branches the most; young shoots generally contain less than old trees. The inorganic matter may not be equally distributed in the same piece of wood: thus, one portion of a piece yielded 2·64, and another only 0·69 per cent. The same result was obtained by the incineration of ten other specimens.¹

⁶ *Comptes rendus*, 1847, xxiv. 269.

⁷ *Bondinage de jeunes brins*. *Bois de rondinage* means wood sawn across in lengths, but not split into billets.

⁸ *Bois de quartier*. This term is ap-

plied to wood cut in lengths, each of which is split into two or more billets.

⁹ *Ann. de Chim. et de Phys.* s. 3, 1844, x. 150.

¹ *Comptes rendus*, 1847, xxiv. 420.

COMPOSITION OF THE ASHES OF WOOD.

Although numerous analyses of the ashes of various kinds of herbaceous plants are recorded, yet I have found comparatively few of the ashes of wood. The following will suffice for illustration:—

I. TABLE SHOWING THE COMPOSITION OF THE ASHES OF CERTAIN KINDS OF WOOD, BARK, AND LEAVES.

| Constituents per cent. | Beech. | | Pine (Tanne). | | | Young Silver Fir (Fichte). |
|--|--------|-------|---------------|-------|--------------------|------------------------------|
| | Wood. | Bark. | Wood. | Bark. | Leaves. | Leaves. |
| Carbonate of potash | 11.72 | 3.02 | 11.30 | 2.95 | .. | } and NaCl 10.72 |
| Carbonate of soda | 12.37 | | 7.42 | | .. | |
| Sulphate of potash | 3.49 | | trace | | 2.76 | |
| Chloride of sodium | trace | | trace | | .. | |
| | | | | | | [silicate of potash 3.90] |
| SOLUBLE IN WATER PER CENT. | 27.58 | 3.02 | 18.72 | 2.95 | 29.98 ² | 16.57 |
| Carbonate of lime | 49.54 | 64.76 | 50.94 | 64.98 | 15.41 | 63.32 |
| Magnesia | 7.74 | 16.90 | 5.60 | 0.93 | 3.89 | 1.86 |
| Phosphate of lime | 3.32 | 2.71 | 3.43 | 5.03 | 38.36 | } 6.35 |
| Phosphate of magnesia ... | 2.92 | 0.66 | 2.90 | 4.18 | | |
| Basic phosphate of sesqui- oxide of iron | 0.76 | 0.46 | 1.04 | 1.04 | | |
| Basic phosphate of alumina | 1.51 | 0.84 | 1.75 | 2.42 | | |
| Phosphate of protoxide of manganese | 1.59 | .. | MnO, trace | .. | .. | .. |
| Silica | 2.46 | 9.04 | 13.37 | 17.28 | 12.86 | 10.31 |
| INSOLUBLE IN WATER | 69.84 | 95.37 | 79.08 | 95.86 | 70.02 | 83.43 |
| TOTAL SOLUBLE AND INSOLUBLE CONSTITUENTS PER CENT. | 97.42 | 98.39 | 97.75 | 98.81 | 100.00 | 100.00 |
| Ash per cent. of the wood dried at 100° C. | 0.384 | 6.618 | 0.328 | 1.785 | 2.310 | 6.25 |

REMARKS ON THE FOREGOING TABLE. — These analyses were made by Carl Hertwig, and published in the *Annalen der Chemie und Pharmacie*, 1843, xlv. 97 *et seq.* The residue obtained by incineration in each case was treated in the usual way with carbonate of ammonia, in order to convert any caustic lime that might be present into carbonate, so that the material analysed was not what is commonly understood by the word ash. By phosphate of lime is meant a substance of the formula $8\text{CaO}, 3\text{P}^2\text{O}^5$ [$8\text{CaO}, 3\text{P}^2\text{O}^5$]. The author does not give the formulæ of the substances which he designates basic phosphate of alumina and basic phosphate of sesquioxide of iron. The difference in the relative proportions of certain con-

² The other constituents soluble in water not determined.

stituents of the ashes or inorganic matter of pine and fir leaves is remarkable, but no certain conclusion on such a point can be drawn from one or two analyses. Alumina appears in this table as a constituent of wood-ashes, but it is not mentioned in the two following tables relating to the composition of those ashes. No inorganic substance can find its way into a plant except in a state of solution in water, when it is absorbed by the roots; and, certainly, neither rain water nor ordinary mineral water contains any salt of alumina, nor does water impregnated with carbonic acid, which dissolves phosphate of lime or magnesia, dissolve even a trace of phosphate of alumina; and the same may also be said concerning the insolubility of phosphate of sesquioxide of iron in water. But the water of soils may contain certain salts of iron in solution; and although a basic phosphate of sesquioxide of iron is mentioned in the preceding table, yet there is no proof whatever that such a salt existed in the living plant.

II. TABLE SHOWING THE COMPOSITION OF THE ASHES OF CERTAIN KINDS OF WOOD.

| Constituents per cent. | I. <i>Fagus sylvatica.</i> | II. <i>Pinus sylvestris.</i> | III. <i>Pinus sylvestris.</i> | IV. <i>Larix Europæa.</i> |
|--|-----------------------------------|-------------------------------------|--------------------------------------|----------------------------------|
| Potash | 15.80 | 2.79 | 0.93 | 15.24 |
| Soda | 2.76 | 15.99 | 14.59 | 7.27 |
| Lime | 60.35 | 30.36 | 33.99 | 25.85 |
| Magnesia | 11.28 | 19.76 | 20.00 | 24.50 |
| Oxide of manganese, Mn^2O^3 [idem]. | .. | 18.17 | 7.61 | 18.51 |
| Phosphate of sesquioxide of iron, $2Fe^2O^3.3PO^5$ [$2Fe^2O^3.3P^2O^5$] | 1.84 | 5.10 | 2.28 | 6.18 |
| Sesquioxide of iron | .. | .. | 7.73 | .. |
| Phosphate of lime, $3CaO.PO^5$ [$3CaO.P^2O^5$] | 3.99 | .. | .. | .. |
| Sulphate of lime | 2.30 | 3.31 | 5.05 | 2.91 |
| Chloride of sodium | 0.21 | 1.48 | 2.52 | 0.92 |
| Silica | 1.46 | 3.04 | 5.27 | 3.60 |
| Total | 99.99 | 100.00 | 99.97 | 99.98 |
| Ash % in the wood dried at 100° C. | .. | 0.143 | 0.190 | 0.322 |

REMARKS ON THE FOREGOING TABLE.—These analyses were made by Böttinger at Giessen, under the direction of Will, and published in the *Annalen der Chemie und Pharmacie*, 1844, l. 406 *et seq.* I. from Neufchâtel, Switzerland; II., III. and IV. from the vicinity of Giessen, not far from which are dolomite and mines of manganese. The ashes of II., III. and IV. were brown-black, and evolved chlorine copiously when heated with hydrochloric acid. II. was diseased. The ashes of III. were obtained from a tree which had died. In these analyses the calculation has been made after deduction of carbonic acid, charcoal (from imperfect incineration), and sand; but, if proper precautions had been observed in the preparation of the ashes, it is difficult to understand how sand should be present in them.

REMARKS ON THE FOREGOING TABLE.—All the analyses, excepting those of the vine (IV., A. B.), were made under the direction of Will, and published in the *Annalen der Chemie und Pharmacie*, 1845, liv. 341 *et seq.* The analyses of the vine ashes were made by Dr. Franz Hruschauer, professor at Grätz, and published in the same volume, pp. 331 *et seq.* The composition is given exclusive of the carbonic acid and carbon in the ashes obtained. The oak-tree ashes (I.) were from a tree grown in the vicinity of Neufchâtel, in French Switzerland. The vine ashes (IV., A. B.) were from vines grown in Lower Styria. The sea-weeds, of which the ashes were analysed, were collected at the mouth of the Clyde, on the west coast of Scotland. The comparatively large proportion of phosphoric acid in the ashes of the vine, and seeds or nuts of the beech is noteworthy.

PROPORTION OF WATER IN WOOD.

All wood when recently felled contains a large quantity of water, which varies in amount with the nature of the tree, the part of the tree, the season of the year at which it is felled, and, in trees of the same kind, with the place of their growth. When wood is exposed to the atmosphere during a sufficient length of time, under conditions favourable to desiccation, it loses the greater part of its water; but all kinds of wood, however well air-dried, retain on an average from 18 to 20 per cent. of water. This is a point of great practical importance in reference to the direct application of wood as fuel. The amount of hygroscopic water in wood may be ascertained by exposing it to a temperature between 100° and 150° C. until it ceases to lose weight. Violette has determined the proportion of water expelled from wood by desiccation at gradually increasing temperatures, and has given the results in the following table: ³—

TABLE SHOWING THE PROPORTION OF WATER EXPELLED FROM WOOD AT GRADUALLY INCREASING TEMPERATURES.

| Temperature of Desiccation. | Water expelled from 100 parts of Wood. | | | | REMARKS. |
|-----------------------------|--|-------|--------|---------|--|
| | Oak. | Ash. | Elm. | Walnut. | |
| 125° C. | 15·26 | 14·78 | 15·32 | 15·55 | Between 200° and 225° there is slight decomposition, and water alone is not evolved. The statements in works on chemistry that wood contains a given quantity of water can only be exact in so far as they indicate the degree of desiccation. |
| 150° | 17·93 | 16·19 | 17·02 | 17·43 | |
| 175° | 32·13 | 21·22 | 36·94* | 21·00 | |
| 200° | 35·80 | 27·51 | 33·38 | 41·77* | |
| 225° | 44·31 | 33·38 | 40·56 | 36·56 | |

* There appears to be a typographical error in these numbers, which exists in the original, and which I am unable to correct.

The wood which Violette operated upon had been kept in store during two years. In each experiment the specimens were exposed

³ *Ann. de Chim. et de Phys.* s. 3, 1853, xxxix. 307.

during two hours to desiccation in a current of super-heated steam, of which the temperature was gradually raised from 125° C. to 225° C. When wood, which has been strongly dried by means of artificial heat, is left exposed to the atmosphere, it re-absorbs about as much water as it contains in its air-dried state.⁴

The desiccation of wood by exposure to the atmosphere is much promoted by the removal of the bark, in proof of which the following observations, made by Af Uhr in Sweden, may be cited. Trees were felled at the same time in June after the sap had risen, and the wood was left to dry under cover during the four following months; it was in pieces of unequal length and diameter, of which some were *barked* and others left with the *bark entire*. His results are recorded in the following table:—

TABLE SHOWING THE RATE OF DESICCATION OF BARKED AND UNBARKED WOOD.⁵

| | Loss per cent. of the Original Weight of the Wood. | | | |
|-------------------------------------|--|---------|------------|----------|
| | July. | August. | September. | October. |
| Barked stems, felled in June | 34·53 | 38·77 | 39·34 | 39·62 |
| Unbarked stems, felled in June..... | 0·41 | 0·84 | 0·92 | 0·98 |

Thus, after the lapse of three months the barked wood was completely air-dried, whereas the unbarked wood had not even lost 1 per cent.⁶ On the other hand, teak-wood (*Tectona*), cut in the form of cubical blocks 1 foot square, has been weighed annually and found to go on drying and shrinking for at least four or five years after its arrival in England; and similar loss by spontaneous desiccation has been observed to take place in the timber brought in different states of seasoning from the forests of India.⁷

The wood of the youngest branches of any individual tree contains about twice as much water as that of the trunk and older branches.

The following table presents the specific gravity of the wood of various trees, and the proportion of water which it contains before and after atmospheric desiccation: ⁸—

⁴ Schubarth, Handbuch der technischen Chemie, iii. 217.

⁵ The kind of wood is not expressly stated, but from the context it may be inferred that it was either silver or Scotch fir.

⁶ Anleitung zur vorteilhaften Verkohlung des Holzes in stehenden und liegenden Meilern, von Carl David af Uhr, aus dem Schwedischen übersetzt

von Dr. J. C. L. Blumhof, p. 13. Giessen, 1820.

⁷ Report on the Teak Forests of the Tenasserim Provinces, by H. Falconer, p. 15. Calcutta, 1852.

⁸ Extracted from Schubarth's Handbuch der technischen Chemie, iii. 217. It is prepared from the data obtained by Schübler and Neuffer, and Rumford.

TABLE SHOWING THE SPECIFIC GRAVITY AND PROPORTION OF WATER IN VARIOUS KINDS OF WOOD.

| Name of the Tree. | Specific Gravity. | | Percentage of Water. | |
|-----------------------------------|-------------------|------------|----------------------|------------|
| | Freshly felled. | Air-dried. | Freshly felled. | Air-dried. |
| <i>Quercus Robur</i> | 0.7075 | 0.7075 | 34.7 | 16.64 |
| „ <i>var. pedunculata</i> ... | 1.0494 | 0.6777 | 35.4 | .. |
| <i>Salix alba</i> | 0.9859 | 0.4873 | 50.6 | .. |
| <i>Fagus sylvatica</i> | 0.9822 | 0.5907 | 39.7 | 18.56 |
| <i>Ulmus campestris</i> | 0.9476 | 0.5474 | 44.5 | 18.20 |
| <i>Carpinus Betulus</i> | 0.9452 | 0.7895 | 18.6 | .. |
| <i>Larix Europæa</i> | 0.9205 | 0.4735 | 48.6 | .. |
| <i>Pinus sylvestris</i> | 0.9121 | 0.5502 | 39.7 | .. |
| <i>Acer Pseudo-platanus</i> | 0.9036 | 0.6592 | 27.0 | 18.63 |
| <i>Fraxinus excelsior</i> | 0.9036 | 0.6440 | 28.7 | .. |
| <i>Betula alba</i> | 0.9012 | 0.6274 | 30.8 | 19.38 |
| <i>Pyrus Aucuparia</i> | 0.8993 | 0.6440 | 28.3 | .. |
| (<i>Mountain-ash</i> .) | | | | |
| <i>Abies excelsa</i> | 0.8941 | 0.5550 | 37.1 | 17.53 |
| „ <i>pectinata</i> | 0.8699 | 0.4716 | 45.2 | .. |
| <i>Pyrus terminalis</i> | 0.8683 | 0.5910 | 32.3 | .. |
| (<i>Wild service tree</i> .) | | | | |
| <i>Æsculus Hippocastanum</i> ... | 0.8614 | 0.5794 | 38.2 | .. |
| <i>Alnus glutinosa</i> | 0.8571 | 0.5001 | 41.6 | .. |
| <i>Tilia Europæa</i> | 0.8170 | 0.4390 | 47.1 | 18.97 |
| <i>Populus nigra</i> | 0.7795 | 0.3656 | 51.8 | .. |
| „ <i>tremula</i> | 0.7654 | 0.4302 | 43.7 | .. |
| „ <i>fastigiata</i> | 0.7634 | 0.3931 | 48.2 | 19.55 |
| <i>Salix caprea</i> | 0.7155 | 0.5289 | 60.0 | .. |

The degree of dryness will necessarily vary with the state of the atmosphere as to moisture. By air-drying, wood may shrink $\frac{1}{10}$ in volume, or perhaps more.⁹

The proportion of water in wood is least at the fall and beginning of the year, as will appear from the following results:¹—

| Kinds of Wood. | Proportion of Water. | |
|-----------------------------------|----------------------|----------|
| | Jan. 27. | April 2. |
| <i>Abies excelsa</i> | 52.7 | 61.0 |
| <i>Corylus Avellana</i> | 40.9 | 49.2 |
| <i>Æsculus Hippocastanum</i> .. | 40.2 | 47.1 |
| <i>Acer Pseudo-platanus</i> | 33.6 | 40.3 |
| <i>Fraxinus excelsior</i> | 28.8 | 38.6 |

⁹ Karsten's System der Metallurgie, iii. 23.

¹ Schübler and Neuffer, Karsten's System der Metallurgie, iii. 21.

SPECIFIC GRAVITY AND WEIGHT OF WOOD.

Wood being extremely porous, its specific gravity must necessarily vary according to the amount of water which it contains: as the water evaporates, the spaces which it occupied become filled with air, except in so far as they are contracted by shrinking. From the fact of all woods having nearly the same elementary composition, it might be anticipated that the specific gravity of all would be nearly the same; and this is found to be the case when the determination is made with wood of which the pores have been completely deprived of air and afterwards filled with water. The variations in specific gravity, which appear in the preceding table, are in great measure due to the variable proportions of air and water contained in the pores of the wood. After complete expulsion of air, Rumford obtained the following results:—

| | Specific Gravity. | | Specific Gravity. |
|----------------|-------------------|--------------|-------------------|
| Oak | 1·5344 | Pine | 1·4621 |
| Elm | 1·5186 | Birch | 1·4848 |
| Beech | 1·5284 | Lime | 1·4846 |
| Sycamore | 1·4599 | Poplar | 1·4854 |

The following determinations have been made in Prussia of the weight of a cubic foot, in pounds (Prussian),¹ of various kinds of wood in different states of dryness:²—

| | Quite fresh. | Half air-dried. | Quite air-dried. |
|------------------|--------------|--------------------|---------------------|
| Oak | 70 | 60 | 46 |
| Beech | 65 | 50 | 39 |
| Birch | 60 | 50 | 42 |
| Hornbeam | 62 | 56 | 50 |
| Scotch fir | 60 | 48 | 36-26 |

ACTION OF WATER UPON WOOD.

By immersion in water, and subsequent drying, the specific gravity of wood is somewhat diminished. Thus, Werneck found that the specific gravity of beech-wood was 0·56, which, after the wood had been transported by floating in water, was reduced to 0·537; and that similarly the specific gravity of spruce fir was reduced from 0·493 to 0·464.³

It has been ascertained, from trials made in the ovens of the

¹ 1 foot English = 11·65368 inches Prussian.

1 cubic foot English = 1582·667 cubic inches Prussian.

1 pound Prussian = 1·031236623 pound avoirdupois.

² Der Bergwerksfreund, iii. 8.

³ Karsten's System der Metallurgie, iii. 22.

Chemnitz Baking Company, that a volume of unfloated pine-wood (*Fichtenholz*), represented by 100, is equal in practical effect to 112·3 of the same wood floated; but from the following evidence it will be seen that this difference is not, as might be supposed, due to any change in the composition of wood effected by the action of water. The sawdust obtained from a fir-tree (the kind is not distinctly specified) thirty years old, a fortnight after felling, was washed with a large quantity of water in a paper-mill where sawdust was prepared for the manufacture of paper in a pulping-machine, and it would be difficult to imagine a method by which the action of water upon wood could be more thoroughly tested. The ultimate composition of the same sawdust, before and after washing in the manner just described, and subsequent drying between 110° C. and 120° C., was found to be as follows:—

| COMPOSITION OF SAWDUST FROM FIR-TREE. | | | | |
|---------------------------------------|-------------------|-------------------|----------------------|-------------------|
| Not Washed. | | | Washed (Paper-pulp). | |
| | Inclusive of Ash. | Exclusive of Ash. | Inclusive of Ash. | Exclusive of Ash. |
| Carbon | 49·43 | 49·63 | 49·07 | 49·69 |
| Hydrogen ... | 6·09 | 6·11 | 5·97 | 6·05 |
| Oxygen | 44·09 | 44·26 | 43·72 | 44·26 |
| Ash | 0·39 | .. | 1·24 | .. |
| | <u>100·00</u> | <u>100·00</u> | <u>100·00</u> | <u>100·00</u> |

The correctness of the analysis was confirmed by the fact that by evaporating the wash-water to dryness, only a very small quantity of residue was obtained, which yielded from 50 to 60 per cent. of ash. A very minute portion of what was extracted redissolved in water; and the combustible part consisted of resin soluble in alcohol, and of an acid substance having a very astringent taste.

The unfloated and floated pine-wood used at the Joint Stock Chemnitz bakehouse were also analysed, and the results are as follow:—

| COMPOSITION OF PINE-WOOD. | | | |
|---------------------------|---------------|-------|---------------|
| Dried at 110° C. | | | |
| | Unfloated. | | Floated. |
| Carbon | 48·34 | ..... | 50·36 |
| Hydrogen..... | 5·72 | ..... | 5·80 |
| Oxygen | 45·63 | ..... | 43·38 |
| Ash | 0·31 | ..... | 0·46 |
| | <u>100·00</u> | ..... | <u>100·00</u> |
| Water per cent. | 15·0 | ..... | 14·3 |

From these results it will be seen that, with respect to theoretical calorific power, the floated wood was, weight for weight, a little superior to the unfloated; and that the deterioration of wood consequent on floating cannot be explained by any change in its ultimate chemical composition.

But the unfloated and floated pine-wood, the subjects of the preceding experiments, were found to differ in specific gravity, that of the alburnum of the former being 0.446, and that of the alburnum of the latter 0.409, results substantially agreeing with the observations of Werneck above recorded. The pieces of wood used for determining the specific gravity contained nearly the same proportion of water, the unfloated containing 11.9 and the floated 11.5 per cent. The weight, then, of equal volumes of the unfloated and floated wood was as 100 : 91.7, or the volumes of equal weights were as 100 : 109, respectively. Now it has been stated that in practice 100 volumes of unfloated wood have been found equal to 112.3 of floated wood; and hence it has been inferred that this difference of effect is essentially dependent on difference of specific gravity. The reason assigned for the inferiority of the floated wood is, that, as this wood is less dense than the unfloated wood, it must be more porous and contain more air in its pores, and therefore burn away more quickly than the latter; and, owing to the same cause, the formation of combustible gases would be checked, and, consequently, the inflammability of the wood diminished.⁴ This explanation is not, in my judgment, satisfactory.

ON THE RAPIDITY OF GROWTH OF WOOD.

On this subject there are many recorded observations, from which, on account of their importance to the metallurgist in some countries, I introduce a selection.

Chevandier ascertained that on the western slope of the Vosges mountains and in the plain extending from their base, where the Lower Trias (*grès bigarré*) occurs, the average annual production of wood in forests of large beech-trees is about 9 stères (1 st. = 1 cubic metre = 317.849 cub. feet) per hectare (10,000 square metres, nearly 2½ acres). The average weight of dry wood, per hectare, annually produced in these forests amounts to 3650 kilogr. (8047 lbs. avoird.), which contain 1800 kilogr. (3968 lbs.) of carbon, and 26 kilogr. (57 lbs.) of hydrogen in excess of that required to form water with the oxygen of the wood. He has calculated that a bed of coal (containing 85 per cent. of carbon) corresponding to the annual growth of these forests per hectare would have an average thickness of 0.165 mm. (0.006496 inch).⁵

In the department of Ariège, in the French Pyrenees, the following yields in stères per hectare per annum have been obtained. A thick (*bien fourni*) wood of beeches; from 20 to 50 years old, gave 205½; a well-managed wood of beech, alder, and nut-trees, 19 years old, gave 82; a wood of beeches, 12 years old, gave 25.80;

⁴ G. Wunder, *Zeitschrift des landwirthschaftlichen Vereines in Bayern*, 1864, p. 582. Quoted from Wagner's

Jahresbericht, 1864, x. 718 *et seq.*

⁵ *Ann. de Chim. et de Phys.* s. 3, 1844, x. 156.

a wood of beeches, from 15 to 17 years old, gave 63·60; and in another locality a wood of beeches, 12 years old, gave 60.⁶

The produce of woods cut at intervals, i. e. of coppices (*taillis*),⁷ is much influenced by the nature of the ground; the more permeable and hygroscopic it is, the greater the produce. But in woods of large trees the geological influence of the ground disappears. The difference is explained by the fact that in coppices the ground is not so protected from the desiccating action of the sun as in woods, so that it does not so long retain the necessary moisture, and the vegetative season is, consequently, shortened. Chevandier has shown that the influence of moisture is so considerable that silver firs (*scopins*) raised in boggy ground only grow at the rate of 1·80 kilogr. (3·968 lbs.) a year; in dry ground at the rate of 3·40 kilogr. (7·496 lbs.) a year; when watered by rain, at the rate of 8·20 kilogr. (18·078 lbs.) a year; and when watered by running streams, at the rate of 11·60 kilogr. (25·573 lbs.) a year.

The ages at which various trees are stated by Chevandier to attain their maximum of growth are as follow: oak at 77 years; ash at 80 years; silver fir, in very good ground, at 115 years, and in ground of medium quality, at 76 years; Scotch fir, in good ground, at 51 years, and in ground of medium quality, at 50 years. The difference in the last two cases is remarkably small!

In the Black Forest in the Duchy of Baden trees of hornbeam produced annually 2560 kilogr. (5644 lbs.) of dry wood per hectare (2½ acres), and trees of silver fir 3903 kilogr. (8604 lbs.).⁸ These numbers include the wood obtained in thinning the forests, which is estimated at 15 per cent. in addition to the wood obtained in felling the trees. The actual data are recorded in the table on next page.

⁶ Recherches sur le Gisement et le Traitement direct des Minerais de Fer dans les Pyrénées, et particulièrement dans l'Ariège, par M. Jules François, p. 173. Paris, 1843.

⁷ "*Taillis*. Il n'est usité que dans cette locution, *bois taillis*, un bois que l'on

taille, que l'on coupe de temps en temps." (Dict. de l'Académie française, 6th edition.) "Coppice (or copse). A low wood cut at stated times for fuel." (Johnson's Dict. 1805.)

⁸ Chevandier, Comptes rendus, 1847, xxiv. 271, 422.

TABLE SHOWING THE RATE OF GROWTH OF WOOD IN THE BLACK FOREST.*

| Geological Character of the Ground. | Kind of Wood. | Mean Annual Growth per Hectare (2·4711, say 2½, acres) in Cubic Metres and Cubic Feet, in Actual Volume. (1 c. m. = 35·3166 c. f. English.) | Number of Cubic Metres in Apparent Volume, i.e. measured when stacked so as to include Interstitial Space. | Corresponding Quantities of Dry Wood, in Kilogrammes and Pounds. |
|--|--|---|--|--|
| Gneiss, granite, porphyry, Lower Trias (<i>grès bigarré</i>), Upper Trias (<i>marnes tri-sées</i>), Lower Jurassic Limestone (<i>vieux calcaire jurassique</i>), rolled flints | Oak | { 5·221 c. m. 184·388 c. f. } | 7·57 | { 2900·81 kil. 6395 lbs. |
| Gneiss, granite, red sandstone, Lower Trias (<i>grès bigarré</i>), Lower Jurassic Limestone (<i>vieux calcaire jurassique</i>), Upper Jurassic Limestone (<i>nouveau calcaire jurassique</i>), molasse | { Ash (mountains of medium altitude) | { 5·224 c. m. 184·594 c. f. } | 7·57 | { 2994·28 kil. 6601 lbs. |
| Gneiss, granite, porphyry, <i>terrain de transition</i> , Upper Jurassic Limestone (<i>nouveau calcaire jurassique</i>) ... | { Ash (high mountains) ... | { 4·559 c. m. 161·008 c. f. } | 6·61 | { 2574·62 kil. 5676 lbs. |
| Rolled flints | Hornbeam | { 4·008 c. m. 141·549 c. f. } | 5·81 | { 2226·04 kil. 4907 lbs. |
| Gneiss, granite, Lower Trias (<i>grès bigarré</i>), Muschelkalk | Silver fir | { 8·304 c. m. 293·269 c. f. } | 12·04 | { 3394·21 kil. 7483 lbs. |
| Granite, Lower Trias (<i>grès bigarré</i>), Muschelkalk, rolled flints | Scotch fir | { 7·330 c. m. 158·871 c. f. } | 10·63 | { 2798·71 kil. 6170 lbs. |

In Sweden and Norway the forests chiefly consist of Scotch fir; spruce fir and birch occur in much less proportion, and even the silver fir is not common in several provinces. The annual yield varies considerably, ranging from 3 to 8 stères per hectare (105·950 to 282·533 cubic feet per 2½ acres). In those parts of Sweden which do not notably exceed 60° of latitude, 6 stères (211·900 cubic feet) may be taken as the average.

I am indebted to my friend Mr. Gustav Ekman, of Filipstad, in Sweden, for the following information on this subject (September 1872). The wood used in Sweden for charcoal-making is got from spruce and Scotch fir. Larch has been planted and grows well, but it is not yet known whether it will produce good charcoal. White birch, poplar (*Populus tremula*), and *Alnus incana* are exceptionally used for the same purpose. Oak, beech, and *Corylus* grow but sparingly in the iron-making districts, and cannot be said to be employed for charring. A growth of 50 cubic feet of solid wood per Swedish Tunmland (56,000 square feet), that is, about 25,000 cubic

* In this table no account is taken of the intermediate products resulting from thinnings (*éclatrics*), which would increase the numbers given above by about 15 per cent.

feet per English square mile, is considered to be good, a growth of 12,500 cubic feet very low, and of 75,000, one of the highest. In the north of Sweden it is probably under 12,500. In some parts of the country wood is cut for charcoal-making at the age of 30 years, or a little over; but, in other and more numerous districts, at a much greater age, 60 to 80 years at least. The wealthier landed proprietors take good care of their woods, but on the whole the stock of wood in the Swedish forests is fast diminishing.

According to Durocher, in latitudes bordering on 60° N. lat., the diameter of a pine (*pin*) 25 years old is only 11 centimetres (4·33 inches): whereas, on tolerable land in France and Germany, the annual growth during this first stage of the life of the tree is half as much again. Wood intended for smelting-works is cut at intervals of from 25 to 60 years, which vary with the locality; and when it is to be converted into charcoal, it appears most advantageous to cut the trees at the age of 30 years.¹

According to Werneck the wood of trees which have grown on mountains, under the same conditions (*unter gleichen Umständen*), is more compact than that of trees grown in plains; the wood of closely-grown trees is more compact than that of isolated trees, and the compactness appears to increase in proportion to the dryness of the soil.²

PRACTICAL DIRECTIONS FOR THE CUTTING AND STORING OF WOOD INTENDED AS FUEL.

The trees should be of mature growth, and should be felled when most free from sap. The wood should be cut into suitable lengths, and so stacked as to allow the air freely to circulate through the pile, in order to promote desiccation as much as possible. If uncleaved in the direction of its length, it should be previously deprived of bark, either wholly, or partially. It should be protected from wet and rain; and if transported to a distance in rafts, it should not be left in the water longer than absolutely necessary, because experience has proved that its value as fuel is lessened by long soaking.

¹ Sur l'Exploitation des Mines et des Usines dans le Nord de l'Europe. Par M. J. Durocher. Ann. des Mines, s. 5, 1856, ix. 356.

² Karsten's System der Metallurgie,

iii. 19. It is not clear what conditions are meant. Ueber Verkohlung des Holzes etc., F. Klein, p. 92. Gotha, 1836.

PEAT OR TURF (*Torf*, German; *Tourbe*, French).

The subject of peat is highly interesting in a scientific as well as in a practical point of view, and much has been written upon it in English, German, and French. It is proposed to treat the subject in a general way, and not exhaustively, which would require an entire volume.

NATURE AND MODE OF OCCURRENCE OF PEAT.

Peat is the product of the natural decay of various kinds of plants, under special conditions of moisture and heat, either in swampy ground, actually under water, or in mountainous regions kept moist by fogs. Immense accumulations of peat, constituting *peat-bogs* or *turbaries*, exist in various parts of the world. As peat is composed of the tangled remains of plants in different stages of decay, it may vary much in texture, but is generally so spongy as to contain a large quantity of water. The deeper the peat is taken from the bog or *peat-moss*, as it is sometimes designated, the more condensed it is and the less it retains of vegetable structure, of which, however, sufficient is generally left to be readily distinguishable; and, *cæteris paribus*, the darker it is in colour, the richer it is in carbon.³ It is composed of the same elements as woody tissue, with variable proportions of water and inorganic matter. This matter is in part derived from the inorganic constituents of the plants from which the peat has originated, but is occasionally much increased by the presence of extraneous substances which have been carried into the bog by streams or floods, or blown in by the wind.

VARIETIES OF PEAT.

Somewhat elaborate classifications of the varieties of peat have been proposed, by German writers on the subject, founded on external characters, on the nature of the plants from which the peat has been derived, on its age, on the localities where it has been produced, and on the mode in which it has been extracted. Thus, there is fibrous, earthy, and pitchy peat; moss-peat, and sea-peat or salt-peat (formed in meadows or marshes subject to tidal overflow);⁴ young peat and old peat; lowland- and mountain-peat; cut-peat, and mud-peat or dredge-peat. As the transition from the recently dead moss or other plants, constituting the source of peat, to peat in the most advanced stage of change is perfectly gradual, peat might be expected to vary greatly in quality, as is the case.

³ Dr. Bennett. Trans. of the Royal Society of Edinburgh, 1854, xxi. 183.

⁴ Such peat may be produced from sea-weeds, grass-wrack (*Zostera marina*), salt-wort (*Salicornia herbacea*), black saltwort (*Glaux maritima*), etc.

ANTIQUITY OF PEAT.

It is certain that peat exists which is of great antiquity, in the historical, but not the geological, meaning of that word. Roman roads have been found covered with peat 12 metres in thickness, of which it has been computed, though not demonstrated, that the annual growth was at the rate of from 5 to 6 millimetres. In sinking a well near Rotterdam no fewer than seven beds of peat were discovered, each several metres thick, and the lowest at a depth of 35 metres.⁵ But the rate of growth of peat is probably subject to considerable variation, according to local conditions. As an instance of rapid growth I may mention the following fact, communicated to me by my friend Mr. Hemans, who has had great experience in dealing with Irish peat-bogs, in the construction of railways:—in a locality in Ireland, where water covered the ground thirty years ago, as shown in the ordnance map of that date, there is now (April 1872) a bed of peat 15 feet thick, over which a railway passes.

SPECIFIC GRAVITY AND WEIGHT OF PEAT.

It must obviously be subject to much variation from several causes, such as difference in structure, degree of desiccation, proportion of earthy matter, state of decomposition, and mode of preparation. According to Vogel, the specific gravity of some kinds, when air-dried and inclusive of interstitial space, is as low as 0.25, while of others, which also have not been compressed, it ranges from 0.6 to 0.9.⁶ According to Johnson, the specific gravity of peat in the air-dried state ranges from 0.11 to 1.03.⁷

The weight of a cubic yard of various kinds of air-dried Irish peat is, according to Sir Robert Kane, as follows:—Light peat, so much used for domestic fuel, about 500 lbs.; good peat, packed close in the form of sods, about 900 lbs.; and the densest peat, well packed, as much as 1100 lbs.⁸ Other statements concerning the weight of air-dried peat are as follow:—The weight of a cubic metre of air-dried peat varies from 250 kilogr. for mossy peat to 450 for the blackest kind.⁹ The weight of a cubic metre of slightly altered mossy peat

⁵ French translation of the 1st edition of this work, i. 379. See also *Journ. des Mines*, 1832 (pt. 2), pp. 50 *et seq.* in which is recorded the discovery of peat under a Roman road in Picardy.

⁶ *Der Torf, seine Natur und Bedeutung. Eine Darstellung der Entstehung, Gewinnung, Verkohlung, Destillation und Verwendung desselben als Brennmaterial.* Von Dr. August Vogel, Professor in München, p. 24. Braunschweig,

1859. This is a comprehensive treatise in 170 pages, well illustrated with wood engravings.

⁷ *Peat and its Uses as Fertilizer and Fuel*, by Samuel W. Johnson, A.M., Professor of Analytical and Agricultural Chemistry, Yale College, p. 95. New York, 1866.

⁸ Sir Robert Kane, *The Industrial Resources of Ireland*, p. 37. Dublin, 1845.

⁹ French translation of the 1st edition of this work, i. 384.

ranges from 112 to 263 kilogr.; of peat more changed, but still designated young peat by the Germans, it ranges from 260 to 672 kilogr.; and of old peat, varying in colour from brown to pitch-black, it ranges from 414 to 902 kilogr. in what is called earth-peat, and from 620 to 1034 kilogr. in what is called pitch-peat, which may be regarded as the link between peat and brown-coal or lignite.¹

ACTION OF FROST ON PEAT.

Frozen fresh peat does not contract when it dries after thawing, as does the same peat unfrozen, but is light and very friable; and when frozen peat after thawing is left exposed to the action of moisture, without having been previously dried, it speedily disintegrates and is reduced to soil-like matter. If a bog be deprived of its natural cover of living plants, the uppermost layer of peat so denuded may suffer from frost in the manner described, and be rendered comparatively worthless. Peat, however, may be exposed to frost with impunity, provided it be only moderately dry; but, not so, peat, which after desiccation has been again wetted. From what precedes, it is obvious that the time of getting peat must be regulated by the seasons.²

GEOGRAPHICAL DISTRIBUTION OF PEAT.

IN EUROPE.—Peat is found in many localities in Great Britain and Ireland. It is abundant in the northern and central parts of France, in Sweden, Holland, Denmark, North Germany, Bavaria, various localities in Austria, especially Bohemia, and in Russia. It occurs both in mountainous districts and in low grounds near the sea, as well as inland; and it is stated that while in mountainous districts it seldom exceeds 4 feet in thickness, on low ground, it may acquire a thickness of even 60 feet.³ Peat, however, of much greater thickness than 4 feet is known to exist at a considerable altitude: thus, on Knocklaid, in the county of Antrim, which is 1685 feet above the sea-level, there is a bed of peat nearly 12 feet thick; but in this case the bog rests upon clayey ground, which has resulted from the decomposition of the underlying rock; and it has been observed that bogs are small and shallow where they rest directly upon quartz rock.⁴

In Ireland, of which the total area is 20,000,000 acres, it was estimated, in 1845, that the total area of bogs was 2,830,000 acres, or nearly one-seventh of the entire surface of the island, comprising

¹ Karmarsch, *Handwörterbuch der reinen und angewandten Chemie*, 1861, viii. 933.

² Johnson, *Peat and its Uses*, pp. 105 *et seq.*

³ My friend Mr. Hemans, civil-engineer,

informs me that the peat in the central bog of Westmeath, near Mullingar, is 60 feet thick (April 1872).

⁴ Kane, *The Industrial Resources of Ireland*, p. 35.

1,576,000 acres of what is termed *flat-bog*, and 1,254,000 acres of *mountain-bog*. The flat-bog is spread over the central portion of the great limestone plain, and the mountain-bog is principally distributed through the hilly country along the coast; but in an industrial point of view, it is the central district of bogs which deserves attention.⁵

In some cases it has been observed that forests have grown over peat-bogs, and in others that peat has accumulated in forests and finally destroyed them. Thus the fir-trees occurring in Irish bogs have generally 6 or 7 feet of compact peat *under* their roots, and they are found standing as they grew. But in the case of oaks the opposite is the fact; for their stumps are commonly found resting on the gravel at the base, or on the sides of the small hillocks of gravel and sand, which so often stud the surfaces of bogs, and have been aptly called "islands."⁶

In excavating recently for a tunnel to convey sewage from Barking in Essex, with a view to irrigation, a bed of black peat, from 3 to 6 feet thick, was cut at a depth of from 6 to 8 feet from the surface of the ground, and was found to contain, imbedded, numerous logs or trunks of yew in good preservation, but not of large girth. I visited the spot at the time in company with my friend Mr. Hemans, the engineer of the work.⁷

European peat is chiefly derived from mosses belonging to the genus *Sphagnum*.

IN AMERICA.—In the United States of America, peat beds are stated to occur only in low places, where streams become obstructed and form swamps, or in salt-water bays and inlets, where the flow of the tide furnishes the requisite moisture. Beavers have produced many peat-bogs by building their dams across rivers, so as to flood adjacent forests and convert the ground into a swamp. In the great forest of northern New York may be observed the formation of peat-swamps, as a result of beaver-dams, of the filling of shallow ponds, or of the narrowing of river-courses. The warmth of summer and the dryness of the atmosphere prevent, it is alleged, the accumulation of peat above the highest level of the standing water of the marshes. Springy hill-sides, which in cooler, moister climates would become moors, there dry up in summer to such an extent that no peat can be produced upon them. The formation of peat may take place in water of some depth, and greatly depends upon the growth of aquatic plants, of which the most conspicuous in the Eastern States

⁵ Ibid.

⁶ Portlock, On the Ordnance Survey of Londonderry, quoted by Kane, *ibid.* p. 33.

⁷ I have received from Mr. Hemans the following details of the measures cut through: they are stated below in their proper order:—

| | |
|--|--------------|
| Alluvial clay..... | 6 to 8 feet. |
| Peat with logs of pine and yew..... | } 3 " 6 " |

| | |
|---|----------------|
| Black mud, sometimes con- taining bones..... | } 2 to 3 feet. |
|---|----------------|

| | |
|------------------------------|---------|
| Gravel | 3 " 6 " |
| Stiff clay (London clay) ... | below. |

The bed of gravel gradually rises towards the Barking Hills, and the other strata above it disappear. I have had a microscopic section made of a piece of the wood from the bed of peat, and found it to be yew.

are arrowhead (*Sagittaria*), duckweed (*Lemna*), pickerelweed (*Pontederia*), pondweed (*Potamogeton*), various *Polygonums*, and especially the waterlilies (*Nymphaea* and *Nuphar*). Peat-beds are found from the Atlantic to the Missouri, along and above the fortieth parallel, and appear on the eastern coast at least as far south as South Carolina. The great "Dismal Swamp," in 36° 8' N. lat., between Virginia and North Carolina, is a peat-bog, composed of black peat to the depth of 15 feet, without, it is said, any admixture of earthy matter;⁸ and other swamps on the coast, as far south as Florida and the Gulf, are probably similar in character.

Peat is also found in South America, but it is stated not to contain any remains of mosses.⁹

IN ASIA.—Peat occurs abundantly in the Neilgherry Hills in India, which lie between 11° and 12° N. lat., and is there used for fuel. My friend Dr. Cleghorn has presented me with specimens of this peat, cut into prismatic pieces similar to the marketable peat in this country. Colonel Moore informs me that he has had personal experience of the Neilgherry peat-bogs, as his horse was extricated with some difficulty from one of them. According to Piddington, Indian peat, usually called *Bodh Mattee* in Bengal, is formed differently from European peat, and mostly from a single plant, the wild rice (*Oryza sylvestris*) or *Ooree Dhan*, as it is called by the natives. In some parts of the ancient beds of the rivers, or depressions of the soil, which form lakes, called *jheels* in Bengal, sometimes broad and extensive, at other times narrow, but several miles in length, the plant springs up, where the soil is favourable to its growth, during the early part of the rainy season, and, rising with the water, which it covers with its slender leaves, presents the appearance of a green rice field, though the water may be from 10 to 15 feet in depth. In October, when the waters begin to subside, its seed, which is a very sweet small-grained rice, ripens, and the plant gradually dies and sinks down with the waters, which sometimes leave it dry, forming a deep bog matted over with the stalks of the year's growth. These stalks are cut and dragged out in large quantities by the *ryots*, and, after being dried on hurdles over a fire, are stacked up for food for their cattle in the dry months; but vast and often thick beds of the peat remain, which have accumulated during centuries from the first formation of the *jheel*, and in digging through the beds the stems and leaves may be traced in all stages of decay. A few other aquatic plants (*Valisneria*, *Nymphaea*, etc.) may also be detected amongst them. However, as a general rule, most of the peat of the *jheels* is formed from the wild rice plant, which appears to flourish in spots which it has appropriated to itself. Near the borders of the Sunderbunds, and on the western shores of the Hooghly, are found beds of peat, which seem to have been produced by the

⁸ Lyell's Principles of Geology, 1853, p. 724. | paragraph on American peat is almost wholly derived from Johnson's volume on

⁹ The information in the foregoing | Peat and its Uses.

decay of jungle, destroyed by inundations or sinkings of the soil; and beds are also met with in all the lower parts of the Delta, at variable depths, when wells are sunk or canals or tanks are dug; but these beds, if thick enough for working, would require a mining process to extract any quantity of peat from them; thus it is the surface beds, exposed and renewed annually, as above described, which afford the material so extensively used by the *ryots*.¹ According to the late Dr. Falconer, modern peat dug out of the banks of the Hooghly at Calcutta, a few feet below the surface, contains seeds of *Euryale ferox* (which is not known to occur now nearer than Dacca, sixty miles to the north-east), seeds of *Cucumis Madraspatana* and another cucurbitaceous plant, leaves of *Saccharum Sara* and *Ficus cordifolia*, and the bones of birds and fishes.²

In regard to the subject of Indian peat, I have been favoured (February 1873) with the following observations by my friend W. T. Blanford, of the Geological Survey of India, and formerly a student of the Royal School of Mines:—"The peat of the Neilgherry Hills is quite different from that of Bengal; I am well acquainted with both. The former is only found on the parts of the hills above 6000 feet, in a temperate climate, where both the fauna and flora show affinities to those of the Palearctic region, and differ entirely from those of the plains of Bengal. No rice grows on the tops of the Neilgherry Hills: my impression is that the Neilgherry peat consists of decayed moss, as in Europe; the bogs in which it is produced are precisely like English ones. Bengal peat, on the other hand, is formed in a tropical climate, at or below the tide level of the Ganges' estuaries: it is very impure in general, so much so as greatly to impede its use as a fuel. It is formed in *jheels*, which are sheets of water from a few inches to several feet in depth, not in "bogs," and it consists, as Piddington has shown, of entirely different plants from those which compose the peat of Europe. Beds of impure peat, interstratified with clay and sand, underlie Calcutta, and are frequently exposed in excavations."³

Dr. Falconer obtained peat from the bottom of a lake in Cashmere, which is free from the remains of mosses. An analysis of this peat will be found in the table on the following page.

¹ Journal of the Asiatic Society of Bengal, 1854, xxiii. 400.

² Hooker's Himalayan Journals, ii. 341.

³ See a paper by H. F. Blanford, Professor at the Presidency College, Calcutta,

late of the Geological Survey of India, and formerly a student of the Royal School of Mines, in the Journal of the Asiatic Society of Bengal, 1864, xxxiii. 154.

COMPOSITION OF PEAT.

TABLE SHOWING THE PERCENTAGE COMPOSITION OF PEAT FROM VARIOUS LOCALITIES.

| No. | Locality. | Specific Gravity. | Composition exclusive of Water only. | | | | | | Water %. | Charcoal or Coke %. | Composition exclusive of Ash & Water. | | | |
|-----|------------------------|-------------------|--------------------------------------|-----------|---------|-----------|----------|-------|----------|---------------------|---------------------------------------|-----------|--------------------------------|--|
| | | | Carbon. | Hydrogen. | Oxygen. | Nitrogen. | Sulphur. | Ash. | | | Carbon. | Hydrogen. | Oxygen, inclusive of Nitrogen. | |
| 1 | Cappoge, Ireland... | .. | 51.05 | 6.85 | 39.55 | .. | .. | 2.55 | .. | 26.37 | 52.38 | 7.03 | 40.59 | |
| 2 | Kilbeggan, do. | .. | 51.04 | 6.67 | 30.46 | .. | .. | 1.83 | .. | 24.50 | 52.18 | 6.79 | 31.03 | |
| 3 | Kilbaha, do. | .. | 51.13 | 6.33 | 34.48 | .. | .. | 8.06 | .. | .. | 55.62 | 6.68 | 37.60 | |
| 4 | Phillipstown, do. | 0.405 | 57.53 | 6.83 | 32.23 | 1.42 | .. | 1.99 | .. | .. | 58.70 | 6.97 | 34.33 | |
| 5 | Do. do. | 0.669 | 58.48 | 5.90 | 31.47 | 0.85 | .. | 3.36 | .. | .. | 60.48 | 6.10 | 33.42 | |
| 6 | Wood of Allen, do. . | 0.335 | 58.27 | 6.43 | 31.33 | 1.23 | .. | 2.74 | .. | .. | 59.92 | 6.61 | 33.47 | |
| 7 | Do. do. | 0.639 | 56.20 | 5.31 | 29.84 | 0.75 | .. | 7.90 | .. | .. | 61.02 | 5.77 | 33.21 | |
| 8 | Devonshire..... | 0.672 | 54.02 | 5.21 | 28.18 | 2.30 | 0.56 | 9.73 | 25.50 | 29.30 | 59.84 | 5.77 | 34.39 | |
| 9 | Abbeville, France | .. | 57.03 | 5.63 | 29.56 | 2.21 | .. | 5.56 | .. | .. | 60.40 | 5.96 | 33.64 | |
| 10 | Do. do. | .. | 58.09 | 5.93 | 31.37 | .. | .. | 4.61 | .. | .. | 60.89 | 6.21 | 32.90 | |
| 11 | Framont, do. | .. | 57.79 | 6.11 | 30.77 | .. | .. | 5.33 | .. | .. | 61.05 | 6.45 | 32.50 | |
| 12 | Thézy, do. | .. | 50.67 | 5.76 | 34.96 | 1.92 | .. | 6.76 | .. | 36.96 | 54.31 | 6.17 | 39.52 | |
| 13 | Camon, do. | .. | 46.11 | 5.99 | 35.87 | 2.63 | .. | 9.40 | .. | 38.11 | 50.99 | 6.61 | 42.50 | |
| 13a | Hark | .. | 61.86 | 6.73 | 28.91 | 1.41 | .. | 1.09 | .. | .. | 62.54 | 6.81 | 30.65 | |
| 13b | Reichswald | .. | 62.14 | 6.30 | 27.16 | 1.70 | .. | 2.70 | .. | .. | 63.86 | 6.48 | 29.66 | |
| 14 | Cashmere | .. | 37.15 | 4.09 | 23.48 | 2.02 | .. | 33.27 | 10.40 | .. | 55.66 | 6.12 | 35.22 | |

1 to 3.⁴ Sir R. Kane states that it is very usual to find the peat or turf of commerce containing one-fourth of its weight of water; and that when it is dried in the air, under cover, it still retains one-tenth of its weight.

4.⁵ Light surface peat, of a pale reddish-brown colour, containing small roots of heath (*Erica*) and leaves of grasses and sedges. Average thickness of the bog 18 feet; area 6582 acres.

5. Rather dense peat from the same bog as the last. Colour dark reddish-brown. The structure of moss was still distinguishable, but it was difficult to determine the species.

6. Light surface peat, pale yellowish-brown moss, very open-grained and fibrous. Principally composed of *Sphagnum*, *Hypnum*, etc., the species of which were readily distinguishable.

7. Lower layer of the same bog as the last. Compact and dense. Colour deep blackish-brown. Fracture earthy, appearing almost conchoidal, and exhibiting a resinous lustre when rubbed. All appearance of vegetable matter was totally obliterated.

8.⁶ Cut for fuel from the neighbourhood of the Military Prison, Princetown, near Tavistock, Dartmoor, Devonshire. Colour earth-brown; porous and largely intermingled with vegetable fibres of a

⁴ By Sir Robert Kane, *The Industrial Resources of Ireland*, p. 37.

⁵ 4-7. Report on the Nature and Products of the Process of the Destructive Distillation of Peat, considered specially with reference to its employment as a

branch of manufacturing industry. By the Director of the Museum of Irish Industry (Sir R. Kane). 1851.

⁶ By Vaux, *Quart. Journ. of the Chem. Soc.* 1859, i. 318.

light-brown colour, hard enough to be cut with a knife. When heated, the gas evolved gave a brilliant flame with much smoke; the residual coke was much shrunk in bulk, but retained the original shape of the pieces of peat; it was without lustre and pulverulent, and was readily converted into a light bulky white ash, infusible before the blow-pipe.

9.⁷ From Vulcaire, near Abbeville. This peat was in a very advanced state of change; it presented here and there some fragments of vegetables which had kept their form. Colour very dark brown; powder, brown. 1.23 of ashes contained 0.90 of carbonate of lime and 0.33 of clay. The lime did not exist as carbonate in the peat, but was combined, Regnault believes, with some organic acid, such as the so-called humic acid. The carbon, therefore, of the carbonic acid of the carbonate of lime is added to that obtained on the combustion. Before this correction the ash was 8.20 per cent.

10. From Long, near Abbeville. Similar to No. 9. A similar correction was made in this analysis for the carbonic acid in the ashes.

11. From Champ-du-Feu, near Framont (Vosges). This peat was in a little less advanced state of change than Nos. 9 and 10.

12.⁸ Black peat of first quality. Previously to analysis it was air-dried during many months and left in a dry vacuum during 24 hours.

13. First quality. Dried for analysis like No. 12.

13a.⁹ The best and heaviest kind of peat in the Upper Harz, dark-brown, very heavy and compact, and by pressure easily acquired a sort of polish; the remains of *Sphagnum* in small quantity were observed in it.

13b.¹ It is described as a very heavy and compact kind of peat.

14.² This peat was taken by my friend the late Dr. Falconer from the bottom of a lake in Cashmere. It is brown, crumbly, and somewhat like coarse-cut tobacco in texture. It contains the remains of the roots of aquatic plants, but is free from those of mosses. Two analyses of it were made.

It would be easy to add to the number of analyses recorded in the preceding table, but to do so would serve no useful purpose, because peat taken from the same bog at different depths may vary much in composition. Although the analyses in that table are arranged according to locality, and not in the order of deviation from the composition of the original vegetable matter out of which the peat was formed, yet it will be perceived that the relative increase in the proportion of carbon from No. 13 to No. 2, which show the *minimum* and *maximum* proportions of that element respectively, is not accompanied by corresponding changes in the relative proportions

⁷ 9-11. By Regnault, *Ann. des Mines*, s. 3, 1837, xii. 230.

⁸ 12, 13. By M. de Marsilly, *Ann. des Mines*, s. 5, 1857, xii. 406.

⁹ By Websky. From Erdmann's *Journal für praktische Chemie*, 1864, xcii. 71. An article entitled, "Beiträge zur

Erkenntnis der Zusammensetzung und Bildung des Torfes," by Dr. Justus Websky, pp. 65-96.

¹ By Walz, Websky, *op. cit.* 1864, xcii. 72.

² By C. Tookey, in my laboratory.

of hydrogen and oxygen in accordance with a perfectly definite law. However, it may be broadly stated that as the carbon relatively increases the oxygen relatively decreases. In the case of peat, which, let it be assumed, has been produced from only one kind of plant, say a species of *Sphagnum*, it is readily conceivable that from time to time, even in the same locality, conditions may vary somewhat, so as to influence the process of decay, and cause corresponding variation in the ultimate composition of the resulting products. Thus, there may be greater exposure of the vegetable matter to the action of atmospheric oxygen at one time than at another, from temporary lowering of the surface of the water in the bog, owing to diminished rainfall or higher temperature, or to both; and as a consequence, not only greater oxidation, but also some modification in the oxidizing process itself, for the decay which vegetable matter undergoes when it is submerged differs from that which it undergoes when it is freely exposed to the action of the air. The changes in chemical composition which vegetable tissue undergoes during its conversion into peat will presently be considered in detail.

QUANTITY OF WATER IN PEAT.

Peat may absorb and retain water in large quantity, and obviously different kinds of peat must possess this property in different degrees, according as they are light and spongy, or heavy and compact. According to Griesbach, the cellular tissue of *Sphagnum* may imbibe as much as 200 times its own weight of water. Fibrous peat, fresh from the bog, may contain 90 per cent. of water, of which about 70 per cent. is removed by air-drying; but in the earthy and denser kinds the proportion of water is considerably less.³ M. de Marsilly found that thoroughly air-dried peat lost by desiccation in a dry vacuum from 2.17 to 7.20 per cent. of its weight, and in a water-bath at 100° C. from 12 to 20 per cent., the whole of which, however, was not water.⁴

COMPOSITION OF THE ASHES OF PEAT.

The inorganic ingredients of peat, or those which are left by its incineration, so far from being wholly derived from the plants producing it, have certainly in many cases been in great measure washed into the bog by floods, or blown into it by the wind. In some analyses of peat-ashes alumina appears in considerable proportion, but that element is not a normal constituent of plants; and in those instances in which it is reported to have been detected in plants, it is doubtful whether there was not on the part of the analyst either want of skill, or want of care in the preparation of the material operated upon. Websky, moreover, states that although he carefully picked, washed, and shook *Sphagnum*, yet he found, on afterwards analysing it, that

³ Websky, *op. cit.* 1864, xcii. 91.

⁴ *Ann. des Mines*, s. 5, 1857, xii. 405.

he had not succeeded in entirely separating mechanically intermixed foreign inorganic matter, which proved to be mostly sand;⁵ and he admits that in his analysis of the ashes of *Sphagnum* (see p. 214), in which alumina is set down as present, that base had not existed in the tissue of the plant, but was a mechanically mixed impurity.

A series of not fewer than 27 analyses of the ashes of peat from various localities in Ireland has been made in the laboratory of the Museum of Irish Industry, under the direction of Sir Robert Kane; and of these are inserted the four following of the ashes of the varieties of peat, numbered 4, 5, 6, 7 in the preceding table showing the composition of peat⁶ (see table, p. 206). It is stated that the quantity of carbonic acid found by experiment was nearly in every case much less than that required to saturate the lime, admitting the whole of the sulphuric acid to exist as sulphate of lime; and it is inferred that the greater part of the carbonic acid, which is supposed to have been in combination with lime, was expelled during incineration.⁷ According to Regnault the lime in peat is certainly not present in the state of carbonate, but is in combination with an organic acid, such as the so-called humic or ulmic acid; for he states that no effervescence occurs by the addition of an acid to peat.⁸ Websky found that when lime was the chief constituent of peat-ashes, and was not present in the state of gypsum, it existed in combination with humic acid, from which it could not be separated by washing and levigating, but might be immediately dissolved out by hydrochloric acid, without effervescence.⁹

TABLE SHOWING THE PERCENTAGE COMPOSITION OF THE ASHES OF PEAT.

| Constituents. | 4. | 5. | 6. | 7. |
|--|---------|--------|--------|--------|
| Potash | 1·323 | 0·461 | 0·491 | 0·247 |
| Soda | 1·902 | 1·399 | 1·670 | 0·496 |
| Lime | 36·496 | 40·920 | 33·037 | 24·944 |
| Magnesia | 7·634 | 1·611 | 7·523 | 1·285 |
| Alumina | 5·411 | 3·793 | 1·686 | 0·360 |
| Sesquioxide of iron | 15·608 | 15·969 | 13·281 | 19·405 |
| Phosphoric acid | 2·571 | 1·406 | 1·438 | 0·242 |
| Sulphuric acid | 14·092 | 14·507 | 20·076 | 10·742 |
| Hydrochloric acid | 1·482 | 0·983 | 1·747 | 0·335 |
| Silica in compounds decomposable by acids ... | 3·595 | 1·111 | 2·148 | 1·082 |
| Sand and silicates undecomposable by acids | 2·168 | 2·107 | 7·683 | 26·789 |
| Carbonic acid | 7·761 | 15·040 | 8·340 | 13·890 |
| | 100·043 | 99·307 | 99·120 | 99·817 |

⁵ *Op. cit.* 1864, xcii. 82.⁶ Report, *antea cit.* p. 72.⁷ *Idem.* p. 72.⁸ *Ann. des Mines*, s. 3, 1837, xii. 231.⁹ Erdmann's Journal für praktische

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Chemie, 1864, xcii. 86, Websky's article entitled, "Beiträge zur Erkenntniss der Zusammensetzung und Bildung des Torfes."

The results of 23 analyses, nearly all made by Websky and Jäkel, of the ashes of peat from the Harz, from the vicinity of Hamburg and of Berlin, and from other localities in North Germany, have been tabulated by Websky,¹ but they add scarcely anything to the information contained in the preceding table of Kane's analyses. In the 23 analyses, of which several are incomplete, the proportions per cent. of the constituents of the ashes, exclusive of the instances in which nothing or trace is set down against the ingredient, vary within the following limits :—

| Percentage of ashes 0.57 — 22.07 | | | |
|--|--------------|----------------------------|--------------|
| Potash..... | 0.05 — 3.64 | Sulphuric acid | 0.70 — 37.40 |
| Soda..... | 0.16 — 5.73 | Chlorine | 0.06 — 6.50 |
| Lime | 4.50 — 58.38 | Silica (soluble) | 0.02 — 16.00 |
| Magnesia..... | 0.04 — 24.39 | Carbonic acid..... | 2.50 — 30.59 |
| Alumina | 1.14 — 17.30 | Phosphoric acid..... | 0.25 — 8.00 |
| Sesquioxide of iron..... | 0.88 — 73.33 | Residue insoluble in acids | 0.99 — 76.56 |

Oxide of manganese appears only in one of these analyses, and then is put down as a trace.

The nature and proportion of inorganic matter may vary greatly in peat for reasons previously assigned. The dust, sand or clayey matter, blown into a peat-bog may be so fine that after its intermixture with the peat it cannot be separated from it by washing and levigation. Peat formed at high elevations and covering rocky ground, from which but little can be washed out by the rain, where dust from the plains below cannot reach it, and where the bogs may be protected by surrounding forests, as is the case with those of the Harz at an altitude of from 2000 to 3000 feet above the level of the sea, may yield an extremely small quantity of ash.²

PYRITIC PEAT.—Iron-pyrites might be expected to occur, occasionally at least, in peat, and Karsten states that some kinds of peat have been found to contain so large an amount of it as to have been profitably employed in the manufacture of sulphate of iron.³ Websky states that he has never been able to find crystals of iron-pyrites in peat, not even in pieces of peat in which after exposure to the atmosphere he found crystals of gypsum 3 lines in length. Yet it may be inferred that certain kinds of peat contain a considerable quantity of sulphur in combination with iron, because on ignition they evolve the smell of sulphurous acid, and more sulphuric acid exists in their ashes than suffices to saturate the lime which is present (see remarks in the sequel on the formation of sulphuric acid during the incineration of coal), and by exposure to the air they present an efflorescence of sulphate of protoxide of iron. The peat in the ashes of which he found the maximum of sesquioxide given above, namely 73.33 per cent., was the only one in which he did not detect phosphoric acid. The bed of peat at Barking, previously mentioned,

¹ *Op. cit.* 1864, xlii. 95.

² Websky, *idem*, p. 88.

³ *System der Metallurgie*, iii. 91.

which varies from 3 to 6 feet in thickness, is underlaid by a bed of black clay, which loses its blackness by exposure to the air, and which I found evolved a strong odour of sulphuretted hydrogen by the action of hydrochloric acid, and acquired a bluish-grey colour, showing that it probably contained protosulphide of iron. Iron, as Websky suggests, may find its way into a peat-bog in the state of carbonate or sulphate, and from either of these salts sulphide of iron may be generated.

My friend Mr. T. F. Evans, of Amlwch, in the Isle of Anglesey, one of the recently appointed Government inspectors of metalliferous mines, has lately informed me that he has found small cubic crystals of iron-pyrites adhering to the roots of the heather, growing in a peaty bed near Parys Mountain, in the same Isle.

CUPRIFEROUS PEAT.—In peat occurring near Moel-Hafod-Owen, North Wales, copper was found in sufficient quantity to be profitably extracted. The peat was pared off the surface of the bog and burned in kilns, and from the ashes the copper was separated. Many thousand pounds worth of the metal were thus procured.⁴

In the immediate vicinity of Parys Mountain in the Isle of Anglesey a peaty bed, impregnated with copper, was found about sixty years ago. This bed is the same as that in which crystals of iron-pyrites have been found, as above mentioned. The copper-bearing peat is scattered in irregular patches over an area of about 200 acres of bog-land. Both metals, it is believed, occur as sulphides, and they have doubtless been introduced by infiltration of the solution of the sulphates resulting from the weathering action of the coppery minerals exposed on Parys Mountain, where the Parys and Mona mines are situate. Large quantities of this peat have, from time to time, been burned in heaps, and the residual ashes smelted at the Mona Copper-works. The ashes contained about 3 per cent. of copper, and sufficient iron to render them a useful flux for the cherty ores worked at the Mona and Parys mines. The extraction of the copper from the peat has, however, been abandoned. I received this information a short time ago from my friend Mr. T. F. Evans.

ALUMINOUS PEAT.—On the walls of a trench cut in a peat-bog in Sweden a snow-like efflorescence of alum has been observed.⁵

PROXIMATE ANALYSIS OF PEAT.

The following analysis of a brown fibrous peat from St. Wolfgang in Upper Austria has been made by Ferstl.⁶

⁴ Professor A. C. Ramsay, *Journal of the Geological Soc.* 1854, x. 245.

⁵ *Berg- und hüttenmännische Zeitung*, 1864, xviii. 265.

⁶ Kenngott, *Uebersicht*, 1855 (published 1856), p. 153. Extracted from the *Jahrbuch der k.-k. geol. Reichsanstalt*, iv. 152.

1. Soluble in water :—

| | | | |
|--|-------|-------|-------|
| a. <i>Organic matter</i> with trace of ammonia | 1·500 | | |
| b. <i>Inorganic matter</i> : | | | |
| Sulphate of lime | 0·041 | | |
| Chloride of potassium | 0·008 | | |
| Chloride of sodium | 0·007 | | |
| Chloride of magnesium ... | 0·049 | | |
| Sesquioxide of iron | 0·015 | | |
| Alumina..... | 0·013 | | |
| Silica | 0·026 | | |
| | | 0·159 | |
| | | | 1·659 |

2. Soluble in hydrochloric acid :—

| | | | |
|--------------------------------|-------|-------|-------|
| a. <i>Organic matter</i> | 0·126 | | |
| b. <i>Inorganic matter</i> : | | | |
| Phosphoric acid | 1·070 | | |
| Lime | 1·052 | | |
| Magnesia | 0·295 | | |
| Sesquioxide of iron | 0·122 | | |
| Protoxide of manganese ... | 0·047 | | |
| Alumina | 0·312 | | |
| Silica | 0·046 | | |
| | | 2·944 | |
| | | | 3·070 |

3. Insoluble in water and acid :—

| | | | |
|--|--------|------------|---------|
| a. <i>Organic matter</i> : | | | |
| Humic acid | 22·600 | | |
| Humic carbon | 37·700 | | |
| Resin | 4·100 | | |
| Wax | 1·400 | | |
| Vegetable fibre | 16·220 | | |
| | | 82·020 | |
| b. <i>Inorganic matter</i> | 0·290 | | |
| c. <i>Water</i> | 14·500 | | |
| d. <i>Carbonic acid not determined</i> | — | | |
| | | | 96·810 |
| | | Total..... | 101·539 |

The air-dried peat consisted of—

| | |
|----------------------|--------|
| Water | 14·50 |
| Ash..... | 3·48 |
| Organic matter | 82·02 |
| | 100·00 |

M. de Marsilly ascertained that at 100° C. peat suffers decomposition, with the disengagement of products containing carbon and hydrogen in excess of that required to form carbonic acid and water with the oxygen in those products. At 250° C., according to the same observer, peat often ignites.⁷

Reinsch, perceiving during the incineration of peat a sensible

⁷ Ann. des Mines, s. 5, 1857, xii. 405.

odour of cyanogen, tried in consequence to manufacture ferrocyanide of potassium from peat, and he at least established the fact of its production. Websky has confirmed the accuracy of Reinsch's observation, but found the odour to be strongest at the end of the incineration.⁸

ON THE CHANGES IN CHEMICAL COMPOSITION WHICH VEGETABLE TISSUE UNDERGOES DURING ITS CONVERSION INTO PEAT.

It is certain, as previously stated, that in Europe mosses belonging to the genus *Sphagnum* contribute very largely, and sometimes almost exclusively, to the formation of peat, so that their tissue may be regarded as the original material in considering the chemical changes which take place in the formation of peat. The starting-point, then, is the composition of *Sphagnum*, which is given in the following table, along with that of the incipient peat lying immediately underneath.

TABLE SHOWING THE COMPOSITION OF *SPHAGNUM* AND OF INCIPIENT PEAT.*

| No. | Locality. | Analyst. | Composition, per cent., exclusive of Ash. | | | | Ash per cent. |
|------|------------------------|----------|---|-----------|---------|-----------|---------------|
| | | | Carbon. | Hydrogen. | Oxygen. | Nitrogen. | |
| I. | Grunewald, near Berlin | Websky | 49·88 | 6·54 | 42·42 | 1·16 | 3·72 |
| II. | Do. do. | do. | 50·33 | 5·99 | 42·63 | 1·05 | 2·85 |
| III. | Upper Harz | do. | 50·86 | 5·80 | 42·57 | 0·77 | 0·57 |

The material analysed was freed from hygroscopic water by preliminary desiccation.

I. The *Sphagnum* was gathered in June from a bog presenting very luxuriant vegetation (*in einem sehr kräftig vegetirenden Torfmoore*), where, intermixed with a little cotton-grass (*Eriophorum*) and a few rushes, it covered the whole surface of the bog (*Moor*) with a dense carpet.

II. This peat was cut after taking off the uppermost coherent cover, consisting of the living plants. In the moist state it was red-brown, easily friable, and seemed to be much altered, but when dried, it was bright-brown in colour and light in weight; and its individual fibres showed much tenacity, while it had still the appearance of a confused mass of *Sphagnum*, interwoven with some easily discernible roots and stalks of cotton-grass.

III. This peat was cut from the high moors (*Hochmoor*) of the Upper Harz, 2500 feet above the North Sea, and is the lightest in weight found there; it was composed almost entirely of *Sphagnum*, appeared very little decomposed, and had a bright-brown colour.

The ashes of the *Sphagnum* and incipient peat, to which the last

* Erdmann's Journal für praktische Chemie, 1864, xcii. 77.

⁸ Websky, idem, p. 93.

table refers, were analysed, and their composition found to be as follows :—

TABLE SHOWING THE PERCENTAGE COMPOSITION OF THE ASHES OF *SPHAGNUM* AND OF INCIPIENT PEAT YIELDED BY NOS. I, II, III. IN THE PRECEDING TABLE.

| | I. | II. | III. |
|--|--------------------|--------------------|--------------|
| Potash..... | 9.84 | 19.88 | 3.78 |
| Soda | 4.71 | 9.45 | 4.80 |
| Lime..... | 6.69 | 0.96 | 9.79 |
| Magnesia | 3.83 | 6.57 | trace |
| Alumina | 1.74 | 6.74 | 0.21 |
| Sesquioxide of iron..... | 10.19 | 5.14 | 13.59 |
| Oxide of manganese, Mn^2O^3 [idem] | trace | trace | 3.23 |
| Sulphuric acid | 3.70 | 5.59 | 2.83 |
| Chlorine | 3.52 | 5.33 | trace |
| Silica (soluble) | 9.38 | 13.35 | — |
| Carbonic acid | 0.26 | — | — |
| Phosphoric acid | 3.80 | 5.34 | — |
| Residue insoluble in acids, chiefly sand and clay | 41.59 | 15.71 | 61.76 |
| | <u>99.25</u> | <u>94.06</u> | <u>99.99</u> |

Analyses Nos. I. and II. by Websky, and No. III. by Wiegmann. There appears to be a typographical error in No. II. These analyses may usefully be compared with the analyses of the ashes of peat in the table on p. 209. The diminution in the proportion of the alkalis, due to their solubility in water, should be noticed.

In order to make evident the numerical relations existing between the carbon, hydrogen, oxygen, and nitrogen in peat, in the order of progressive deviation from the composition of the tissue of living *Sphagnum*, the following tabular view is presented, in which the carbon is set down at the constant quantity of 100.¹

TABLE SHOWING THE CHANGES IN THE RELATIVE PROPORTIONS OF THE ORGANIC CONSTITUENTS OF *SPHAGNUM* DURING DECAY.

| No. | Substance. | Carbon. | Hydrogen. | Oxygen. | Nitrogen. | Hydrogen in excess of what is required to form Water with the Oxygen. |
|-------|--------------------------|---------|-----------|---------|-----------|---|
| I. | Original <i>Sphagnum</i> | 100 | 13.1 | 85.0 | 2.3 | 2.48 |
| II. | Peat..... | 100 | 11.9 | 84.7 | 2.1 | 1.32 |
| III. | „ | 100 | 10.1 | 70.2 | 4.5 | 1.33 |
| IV. | „ | 100 | 11.9 | 55.5 | 3.5 | 4.97 |
| V. | „ | 100 | 9.5 | 55.3 | 4.3 | 2.59 |
| VI. | „ | 100 | 8.8 | 53.7 | 4.9 | 2.09 |
| VII. | „ | 100 | 10.9 | 52.9 | 4.2 | 4.29 |
| VIII. | „ | 100 | 9.8 | 52.5 | 4.2 | 3.24 |
| IX. | „ | 100 | 11.0 | 46.7 | 2.2 | 5.17 |
| X. | „ | 100 | 10.4 | 43.9 | 2.5 | 4.91 |

¹ The details are abstracted from a table compiled by Websky, *ibid.* p. 94.

The varieties of peat referred to in this table were obtained from different localities; and it is not to be supposed that in every instance the peat was derived *exclusively* from the same vegetable material, and that the conditions of its formation were identical and constant. Hence, for reasons previously given, the variations in the proportions of hydrogen and oxygen in relation to the carbon should not be expected to indicate an absolutely precise law. Besides, some allowance must be made for error in analysis. The results, however, are sufficiently approximate to the truth to justify conclusions of a general nature.

It will be seen from the table in question that there is a steady increase in the relative proportion of the carbon to that of the oxygen, but that the ratio between the hydrogen and carbon is somewhat variable.

In the numbers expressing the relative proportions of nitrogen it is not possible to trace any law regulating the elimination of that element.

It has been demonstrated that the conversion of vegetable tissue into peat is accompanied with the evolution of marsh-gas and carbonic acid. At the depth of a foot from the surface left, after cutting away the peat eighteen years previously, in a bog at Grunewald, covered very thickly with *Sphagnum*, Websky observed fine black mud and a lively evolution of bubbles of gas, some of which he collected and found to consist of the following gases by volume and by weight.²

COMPOSITION OF GASES EVOLVED FROM PEAT-SOIL.

| | Volume. | Weight. |
|---------------------|---------------|----------------------|
| Carbonic acid | 2.97 | 5.57 (carbon 1.52) |
| Marsh-gas..... | 43.36 | 30.04 {carbon 22.53} |
| | | hydrogen 7.51} |
| Nitrogen | 53.67 | 64.39 |
| | <u>100.00</u> | <u>100.00</u> |

In weight, it will be observed, the hydrogen is to the carbon as 1 : 3.2. Hence, if the gas collected and analysed by Websky represented the mean composition of the gases, exclusive of nitrogen, evolved during the formation of peat, the loss of carbon would be somewhat more than three times as great as the loss of hydrogen. But as carbonic acid dissolves in water to a much greater extent than marsh-gas or nitrogen, it is not to be expected that an analysis of bubbles of gas evolved from a peat-bog would correctly indicate the true proportion of the gases produced; and, moreover, the probability is that hydrogen is separated in the state of water as well as in that of marsh-gas.

Let us compare the composition of *Sphagnum* (No. I. in the table) with that of peat most advanced in decay (No. X.), excluding the nitrogen, which is very nearly the same in each.

² Idem, p. 76.

| | | | |
|--------|------------|---------------|-------------|
| No. I. | Carbon 100 | Hydrogen 13.1 | Oxygen 85.0 |
| No. X. | „ 100 | „ 10.4 | „ 43.9 |

Now,

$$10.4 \text{ H (No. X.)} : 100 \text{ C (No. X.)} :: 13.1 \text{ H (No. I.)} : 125.9 \text{ C,}$$

and,

$$10.4 \text{ H (No. X.)} : 43.9 \text{ O (No. X.)} :: 13.1 \text{ H (No. I.)} : 55.29 \text{ O.}$$

The composition, then, of No. X., taking hydrogen equal to 13.1, would be—

| | | |
|--------------|---------------|---------------|
| Carbon 125.9 | Hydrogen 13.1 | Oxygen 55.29, |
|--------------|---------------|---------------|

and that of No. I. is—

| | | |
|------------|---------------|--------------|
| Carbon 100 | Hydrogen 13.1 | Oxygen 85.0. |
|------------|---------------|--------------|

Hence, it appears that in the conversion of the substance of No. I. into that of No. X. the ratio between the hydrogen and carbon has changed from 1 : 7.63 to 1 : 9.61, and the ratio between the hydrogen and oxygen has changed from 1 : 6.49 to 1 : 4.22; or, otherwise stated, the conversion of No. I. into No. X. was attended with a relative increase in the proportion of carbon and a relative decrease in that of oxygen to the hydrogen present.

It is possible to show how vegetable matter, say, like that which constitutes the tissue of *Sphagnum*, may be the source of peat—of the youngest and least changed peat as well as of the oldest and most changed—by the formation exclusively *from that matter* of marsh-gas and carbonic acid. But it cannot be demonstrated that peat is ever wholly produced in this manner, for atmospheric oxygen, either by the direct access of air or in solution in water, must obviously reach the decomposing vegetable matter in a peat-bog, and probably oxidize carbon and hydrogen so as to form carbonic acid and water.

The most general form of the proposition is this:—assuming the hypothetical case, namely, that the chemical changes are produced without the aid of atmospheric oxygen, it is required to find, from the composition of cellulose, the relative weights of marsh-gas and carbonic acid, which must be evolved in order to yield a product of known composition. This computation has been made, in the following way, by C. Law.

It will be remembered that the formula of cellulose is $\text{C}^{24}\text{H}^{20}\text{O}^{20}$ [$\text{C}^{12}\text{H}^{20}\text{O}^{10}$], so that the hydrogen and oxygen are present in the exact proportions required to form water; and, further, that the quantity of oxygen in a fuel is never in *excess* of the amount required to form water with the hydrogen present. Hence for every part by weight of hydrogen, evolved in combination with carbon, as marsh-gas, 8 parts by weight of oxygen must be evolved in combination with carbon, as carbonic acid, in order to yield a product containing no *disposable hydrogen*;* but, if the product does contain disposable hydrogen, as is usually the case, a further quantity of

* This term has been already explained; see p. 156.

oxygen must be evolved, in combination with carbon, as carbonic acid, in proportion to the amount of disposable hydrogen in the product.

The calculation will be made in three steps: first, it will be ascertained what the composition of the product would have been, had it contained no disposable hydrogen; secondly, it will be ascertained what weights of marsh-gas and carbonic acid respectively must have been evolved from a given weight of cellulose in order to yield the product, if it had contained no disposable hydrogen; and, thirdly, it will be ascertained what further quantity of carbonic acid must have been evolved to account for the disposable hydrogen which the product does contain.

Let the composition of the product, neglecting the nitrogen and ash, be as follows:—

| | | | | | |
|-----|-------|----|--------|----|-----------|
| 100 | parts | by | weight | of | carbon, |
| a | „ | „ | „ | „ | hydrogen, |
| b | „ | „ | „ | „ | oxygen. |

Then,

$$a - \frac{b}{8} = \frac{8a - b}{8} = \text{the number of parts by weight of disposable hydrogen;}$$

$$8 \left(a - \frac{b}{8} \right) = 8a - b = \text{the number of parts by weight of oxygen, evolved in combination with carbon, in order to produce the disposable hydrogen;}$$

$$8 \left(a - \frac{b}{8} \right) = 3 \left(\frac{8a - b}{8} \right) = \text{the number of parts by weight of carbon, evolved in combination with the above quantity of oxygen.}$$

If, therefore, there had been no disposable hydrogen, the quantities of carbon and oxygen evolved would have been so much less, and the composition of the product would have been:—

| | | | | | |
|---|-------|----|--------|----|-----------|
| $100 + 3 \left(\frac{8a - b}{8} \right)$ | parts | by | weight | of | carbon, |
| a | „ | „ | „ | „ | hydrogen, |
| $8a$ | „ | „ | „ | „ | oxygen. |

Now, assuming that there is no disposable hydrogen in the product, the marsh-gas and carbonic acid must have been evolved in such proportions that the hydrogen of the marsh-gas is exactly in the ratio required to form water with the oxygen of the carbonic acid; that is to say, the three elements will be evolved in the following proportions, $C^2H^4 + 2CO^2$ [$CH^4 + CO^2$], or—

| | | | | | |
|----------------|-------|----|--------|----|---------------|
| $12 + 12 = 24$ | parts | by | weight | of | carbon, |
| 4 | „ | „ | „ | „ | hydrogen, and |
| 32 | „ | „ | „ | „ | oxygen. |

Or, taking the hydrogen and oxygen together, the number of parts by weight of carbon evolved will be to the number of parts by weight of hydrogen and oxygen evolved as $24 : 4 + 32$, i.e. as $2 : 3$.

But, in cellulose, $C^{24}H^{20}O^{20}$ [$C^{12}H^{20}O^{10}$], the ratio between the weight of the carbon and that of the hydrogen and oxygen, taken together, is as $4 : 5$. The problem, therefore, is to ascertain what weight of carbon, hydrogen, and oxygen, in the ratio of 2 parts of

carbon to 3 of hydrogen and oxygen, taken together, must be removed from cellulose, in order to obtain a product of the composition—

$$100 + 3 \left(\frac{8a - b}{8} \right) \text{ parts by weight of carbon,}$$

| | | | | | |
|----------|---|-----|----|----|-----------|
| together | } | a | ,, | ,, | hydrogen, |
| = 9a | } | 8a | ,, | ,, | oxygen. |

Let x = the number of parts by weight of carbon to be removed for every 100 parts by weight of carbon in the cellulose.

Then $\frac{3}{2}x$ = the number of parts by weight of hydrogen and oxygen, taken together, to be removed for every 125 (since as 4 : 5 :: 100 : 125) parts by weight of hydrogen and oxygen in the cellulose.

Therefore,

$$100 + 3 \left(\frac{8a - b}{8} \right) : 9a :: 100 - x : 125 - \frac{3}{2}x;$$

whence, since a and b are known, the value of x may be deduced. And the number of parts by weight of hydrogen and oxygen, severally, to be removed, are equal to $\frac{1}{9}$ and $\frac{8}{9}$ of $\frac{3}{2}x$.

When disposable hydrogen is present in the product, the number of parts by weight of carbon left, when x has been deducted from 100, has to be further reduced in the ratio of $100 + 3 \left(\frac{8a - b}{8} \right) : 100$; and the number of parts by weight of oxygen which are left, i.e. $\frac{8}{9}$ of $125 - \frac{3}{2}x$, has similarly to be reduced in the ratio of $8a : b$. All the necessary deductions have now been made, and the numbers left are in the ratio of the relative proportions of carbon, hydrogen, and oxygen in the product.

It will be remembered that (omitting the reduction made on account of the disposable hydrogen) half the carbon removed, i.e. $\frac{x}{2}$, is evolved in combination with hydrogen as marsh-gas.

Bearing this in mind, the relative weights of the marsh-gas and carbonic acid evolved can be at once obtained from the foregoing data.

Example.—As an example of the computation which has just been described, the case of No. X. in the table on p. 214 may be selected.

The composition of this peat, neglecting the nitrogen and ash, is as follows :—

| | | | |
|-------|-------|-----------|------------|
| 100.0 | parts | by weight | of carbon, |
| 10.4 | ,, | ,, | hydrogen, |
| 43.9 | ,, | ,, | oxygen. |

Therefore there are

$$10.4 - \frac{43.9}{8} = 4.9125 \text{ parts by weight of disposable hydrogen;}$$

$4.9125 \times 8 = 39.3$ parts by weight of oxygen, evolved in combination with carbon, in order to produce the disposable hydrogen;

$4.9125 \times 8 = 14.7375$ parts by weight of carbon, evolved in combination with the above quantity of oxygen.

If, therefore, there had been no disposable hydrogen, the quantities of carbon and oxygen evolved would have been so much less, and the composition of the product would have been—

| | | | | |
|------------|------|----------|----------------------------|-----------|
| | | 114·7375 | parts by weight of carbon, | |
| together } | 10·4 | ,, | ,, | hydrogen, |
| = 93·6 } | 83·2 | ,, | ,, | oxygen. |

In order to obtain a product of this composition, x parts by weight of carbon, and $\frac{3}{2}x$ parts by weight of hydrogen and oxygen, taken together, must be removed from cellulose (assumed to consist of 100 parts by weight of carbon and 125 parts by weight of hydrogen and oxygen, taken together).

x is found from the following ratio :—

$$114\cdot7375 : 93\cdot6 :: 100 - x : 125 - \frac{3}{2}x.$$

$$(100 - x) \times 93\cdot6 = \left(125 - \frac{3}{2}x\right) \times 114\cdot7375,$$

whence, $x = 63\cdot46$

and $\frac{3}{2}x = 95\cdot19.$

Making these deductions, there are left—

$$100 - 63\cdot46 = 36\cdot54 \text{ parts by weight of carbon,}$$

$$(125 - 95\cdot19) \frac{1}{9} = 3\cdot31 \quad ,, \quad ,, \quad \text{hydrogen,}$$

$$(125 - 95\cdot19) \frac{8}{9} = 26\cdot50 \quad ,, \quad ,, \quad \text{oxygen.}$$

And on account of the disposable hydrogen, the carbon must be further reduced in the ratio of 114·7375 : 100; that is, from 36·54 to 31·85 parts by weight; therefore the further quantity of carbon to be deducted is 4·69 parts by weight.

And from the remaining quantity of oxygen, in like manner, 12·51 parts by weight must be deducted, this being the weight of oxygen required to form carbonic acid, with 4·69 parts by weight of carbon.

The following statement, therefore, shows the total quantities of carbon, hydrogen, and oxygen which must have been removed from 225 parts by weight of cellulose, to yield, without the aid of external substances, the product under consideration.

| Cellulose. | Product. |
|----------------------------------|---|
| 100·00 - (63·46 + 4·69) = 31·85 | $\left\{ \begin{array}{l} 100\cdot0 \text{ parts by weight of carbon.} \\ 10\cdot4 \quad ,, \quad ,, \quad \text{hydrogen.} \\ 43\cdot9 \quad ,, \quad ,, \quad \text{oxygen.} \end{array} \right.$ |
| 13·89 - 10·58 = 3·31 | |
| 111·11 - (84·61 + 12·51) = 13·99 | |

And, on the assumption that marsh-gas and carbonic acid are alone evolved, of the above quantities—

$$\frac{63\cdot46}{2} + 10\cdot58 = 42\cdot31 \text{ parts by weight are marsh-gas, and}$$

$$\frac{63\cdot46}{2} + 4\cdot69 + 84\cdot61 + 12\cdot51 = 133\cdot54 \text{ are carbonic acid.}$$

EXTRACTION OF PEAT.

Peat is usually of such consistency that, when the bog in which it occurs admits of being suitably drained by the cutting of trenches or otherwise, or does not require artificial drainage at all, it can be extracted by hand with the use of simple and appropriate tools; and, for the most part, it has been so extracted from time immemorial. But there are localities in which these favourable conditions do not exist, and then it becomes necessary to have recourse to dredging.

Peat, in being extracted by hand, is cut into prismatic pieces, which, it is presumed, are familiar to the readers of this work, and which, for the sake of convenience, will henceforth be designated by the word "peats." The superficial covering of living, or only slightly decomposed, coarsely fibrous vegetable matter must be pared off and thrown aside, as it is comparatively valueless for fuel. A straight trench with vertical sides, and of convenient length, breadth, and depth, is dug in the part so cleared, after which the peat may be cut from each side vertically downwards, which is the usual course, or horizontally and parallel to the trench. One writer states that peat is most easily cut in a vertical direction, but that when it is made up of layers, the sods are liable to break apart at the junction of these layers; and, therefore, horizontal cutting is pronounced to be the best for stratified peat.³ Another writer asserts that, while horizontal cutting is the most convenient for the workman, the peats so cut are liable to break more easily, especially if they consist of two layers differing somewhat in consistency.⁴ Hence it will be seen that even on such an apparently simple question, whether it is best to cut peat horizontally or vertically, unanimity does not exist; and that the reason advanced by one writer in favour of cutting in one direction is identical with that urged by another in favour of cutting in the opposite direction. The peats are carefully removed and arranged so that they may be gradually air-dried.

It is obvious that the thinner peats are cut, the more quickly will they dry. This is a point of great practical importance, and deserves special attention. It is stated that in Bavaria much of the peat, there used for locomotives, is less on an average than 2 inches in thickness.⁵

CUTTING PEAT BY HAND IN HANOVER.

It is asserted that nowhere has the extraction of peat been more skilfully and more economically conducted than in East Friesland, in Hanover; and as the detailed account of the process, published several years ago by Schröder, has been widely circulated in

³ Johnson, *Peat and its Uses*, p. 109.

⁴ French translation of the 1st edition of this work, i. 386.

⁵ Report of Commission for Investigation of Improved Peat Fuel Manufacture, 1872. Dublin, 1873.

various languages, and generally accepted as important in a practical point of view, it is inserted in this place; and, further, the author has met with nothing better of its kind.⁶ It is stated that the price of peat is not so high in this locality as in many other countries where wages are considerably lower, a fact which is ascribed to more skilful organization of labour in getting the peat and preparing it for the market.

The bog, it is assumed, will admit of being drained by simple trenching. The peat is gotten in lengths, 10 feet wide and from 100 to 1000 paces long, excavated crosswise, i. e. in the direction of the width, so that the working face is 10 feet broad. It is wholly extracted, either in one working or, if the bed be too thick for that method, in one or more successive courses. Usually only one length of the dimensions above given is cut in a year from the same bog. In the following year another similar length by the side of the former is excavated, the trench, made by the removal of the peat, thus yearly increasing 10 feet in width; and the useless stuff, pared off the surface to the depth of 1 or $1\frac{1}{2}$ foot, is thrown into the worked-out space with a view to its future cultivation, and in order that the walls of the trench may receive some degree of support, and their tendency to break off and fall down be diminished, an evil which adds much to the difficulty of getting the peat. Five workmen are employed, whose labour is distributed as follows. One man, the *clearer*, removes with a spade, from the surface of a length pared the year before, a layer about 2 inches thick, which has been weathered by atmospheric action, especially by frost. Two men, the *cutters*, are engaged in cutting the peat, of whom one stands on the top and thrusts straight down a long-handled heavy iron tool, which cuts sods 17 inches long and 5 wide, whilst the other, standing underneath, using a light wooden spade pointed with iron, cuts the peat horizontally of the thickness of $5\frac{1}{2}$ inches, and conveys it on a board to the margin of the trench; and from time to time these men change places with each other. Each peat so obtained measures $\frac{1}{2}$ cubic foot, and, when fresh, weighs from $12\frac{1}{2}$ to 13 lbs. (The Hanoverian foot is divided into 12 inches, and is equal to $11\frac{1}{2}$ English inches; and the Hanoverian pound is equal to 1.0731 lb. avoirdupois.) Expert workmen will cut about 25 of such peats or $6\frac{1}{2}$ cubic feet in a minute. A fourth man, the *barrow-loader*, takes the peats where they are left by the cutters, and with the assistance of the first man piles them in wheelbarrows, one upon another, in two rows of six each to a load, which therefore weighs about 150 lbs. The fifth man, the *barrow-wheeler*, with the help of the first, wheels away the peats, and, by simply upsetting the barrow, arranges them, for draining and drying, over the surface of the bog, on one side of the trench, previously cleared and prepared

⁶ Zur Torfbereitungsfrage; von F. H. Schröder, Lehrer an der Baugewerkschule zu Nienburg an der Weser. Dingler's Polytechnisches Journal, 1860, clvi. 128-140.

for that purpose, in rows of sixteen each, and at right angles to the direction of the trench, each row beginning at the distance of 10 feet and extending to the distance of 50 feet from the trench. The fifth man may also be set to work at clearing off the useless stuff from the surface of the bog, along the same side of the trench, to the extent of 10 feet from it, that is, up to the commencement of the rows of peats placed for drying, so that this length of bog may be made ready for cutting during the following year. By moderate labour 3000 cubic feet or 12,000 peats may be cut daily; and this quantity is said to be a day's work for five men, and is taken as *the day's work* in contracts with the workmen. Skilful workmen, by extra labour, will perform the day's work in from 8 to 10 hours; when the extraction cannot be carried on during the whole day, as often happens, such workmen will by labouring 15 hours daily [*on some days*] get 7 days' work in 5, that is, 4200 cubic feet or 16,800 peats a day, somewhat more than 210,000 lbs. or 90 tons, which divided amongst the five men is at the rate of about 18 tons per man. When the peat to be cut is not more than 4 or 5 feet thick, five workmen suffice, but, in extracting double that thickness of peat at the same time, an additional workman is required, and the extraction is effected in two courses. Peat to the depth of 4 feet is first extracted, and as provision must be made for drying this as well as that to be afterwards cut out in the second and lower course, the peats gotten in the first course must be carried far enough away from the trench to leave an intermediate space for those of the second course, a space of 10 feet from the edge of the trench being always kept free with a view to next year's working. After taking out the peat along a short portion of a length to the depth of 4 feet from the surface laid bare by the removal of the overlying useless stuff forming a layer about $1\frac{1}{2}$ foot thick, the extraction of the second layer of that portion is proceeded with. The organization of labour is the same as in cutting a single course of peat, with the exception of that relating to the sixth man. In getting the second and lower course of peat 4 feet thick, the cutters would not be able to throw up the peats fast enough for the wheeler without the aid of the sixth man, the *helper*, who now stands on the top of the second course, where the first course has last been taken off, and catches on a broad wooden shovel the peats thrown up to him by the cutters below, and tosses them to the loader above. This man also acts as a second wheeler in conveying the peats to the drying-ground. The peats, after having been left for a certain time upon the drying-ground, are carried away by women and gradually built up by them in high wall-like rows, a peat and a half thick, care being taken to let one row become somewhat dry before another is piled upon it. In ordinary weather the peats so arranged are left to dry further for about a month; and when they appear to be dry, but when in reality they are only half dry, they are either carted from the bog to be stored up in magazines, or, as is usual in East Friesland, piled up in large stacks on the bog itself, and there left to be further air-dried. A good work-

woman can deal with 12,000 peats daily, that is, the number gotten by a gang of five men. When the weather is very favourable, the peats may be immediately taken from the wall-like rows and piled up carefully in cylindrical stacks of from 200 to 500 cubic feet in volume, that is, from $\frac{1}{4}$ to $\frac{1}{2}$ a day's work.

The day's work, of 3000 cubic feet of freshly-gotten very good black peat, hardly yields 800 cubic feet of dry peat, while the same volume of light grey peat will yield 2000 cubic feet, and occasionally even more, of dry peat. The volume of a good black peat after drying is at the most $\frac{1}{4}$ of a cubic foot, and the dimensions are 12 inches long, 3 wide, and 3 thick. The weight of an air-dried black peat of average quality, with the usual proportion of from 18 to 20 per cent. of hygroscopic water, and when freshly cut of the dimensions previously stated, is $1\frac{1}{2}$ lb., which indicates a yield of 10 per cent. of air-dried peat from the bog; but in the half-dried condition in which the peat often comes into the market, the weight is often 50 per cent. greater. A peat from the lower part of the bog is, as a rule, heavier than $1\frac{1}{2}$ lb.; and after good drainage, the result of working, when a bed from 8 to 10 feet thick, previously drained superficially, is often reduced 2 feet and more in thickness, the density of the peat is increased so considerably that a dry black peat weighs $1\frac{1}{2}$ lb. and one of the best quality 2 lbs. On an average, in the case of ordinary black peat, the day's work may at the least be taken as 150 Centner, but it may amount to 180 or even 240 Centner (1 Centner = 113.426 lbs. av.).

The cost of cutting, etc. for the day's work (= 3000 cubic feet), exclusive of rent and wear of tools, was, in 1860, as follows (1 Rthlr. or Thaler = 2s. 10 $\frac{3}{4}$ d., and 1 Sgr. or Silbergroschen = 1 $\frac{1}{4}$ d.) :—

| | Sgr. | Rthlr. | Sgr. | Rthlr. | Sgr. |
|---|---|--------|------------------|--------|------------------|
| Two cutters | at 15 to 20 | 1 | 0 | to 1 | 10 |
| One clearer | „ 14 „ 19 | 0 | 14 | „ 0 | 19 |
| One helper..... | } „ 13 $\frac{1}{2}$ „ 18 $\frac{1}{2}$ | 1 | 10 $\frac{1}{2}$ | „ 1 | 25 $\frac{1}{2}$ |
| One barrow-loader | | | | | |
| One barrow-wheeler..... | | | | | |
| Customary payments, including allowance for drink | .. | 0 | 10 $\frac{1}{2}$ | .. 0 | 10 $\frac{1}{2}$ |
| Cost of drying | .. | 0 | 20 | .. 0 | 20 |
| Cost of stacking in circular heaps .. | .. | 0 | 10 | .. 0 | 10 |
| | | 4 | 5 | to 5 | 5 |
| English money | | | | | |
| 12s. 0 $\frac{1}{4}$ d. to 14s. 11 $\frac{1}{4}$ d. | | | | | |

The cost of getting in the first year of opening the bog is higher by about 13 $\frac{1}{2}$ to 18 $\frac{1}{2}$ Sgr. than in succeeding years, so that, without reckoning rent and cost of tools, the cost of the day's work may descend to 3 Rthlr. 15 Sgr., or 10s. 1 $\frac{3}{4}$ d.

Taking the cost of the usual day's work (150 Centner) at the highest figures, 5 Rthlr. 5 Sgr., exclusive of rent, the cost per Centner is about 3 $\frac{1}{2}$ Kreuzer (= 1.05d.); and taking the day's work at

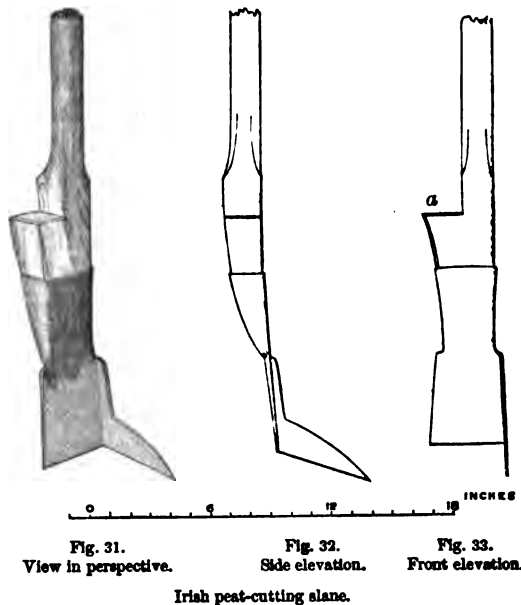
180 Centner, and the cost at 3 Rthlr. 15 Sgr., the cost per Centner amounts only to about 2 Kreuzer ($= 0.6d.$).

Now the cost in Bavaria, where wages were actually lower, amounted, in 1860, to $11\frac{1}{2}$ Kreuzer ($= 3.45d.$) per Centner; and as 1000 of the Bavarian peats weigh 438 lbs., the price per peat is $\frac{1}{3}$ Pfg. ($= 0.048d.$).

As a guarantee for the accuracy of the foregoing figures, it should be stated that they were the result of Schröder's personal experience in managing the working of a bog in East Friesland during two years.

CUTTING PEAT BY HAND IN IRELAND.

The instrument used is shown in the woodcuts, figs. 31, 32, and 33, and is called a *slane*. The cutting part is of wrought-iron, and the handle, the whole length of which is not shown in the woodcuts, is



of wood, about 4 feet long, and without the cross-piece at the top, usual in the English spade. The peat is cut by thrusting the slane vertically downwards, by pressing the foot upon the lateral projecting piece, *a*, of the handle. The following information has been supplied to the Author (June 1872) by Mr. Hemans, to whom he is also indebted for the present of a slane, from which the above woodcuts are taken. With a slane of this kind an able-bodied man will cut about 15 cubic yards of peat daily. He cuts and flings as many peats as will keep two boys or girls employed in catching. The peats or sods are then put into barrows, and wheeled to the nearest

convenient spot, where they may be placed to dry. The peat is generally sold at the place of cutting by the hundred boxes. A box is 20 cubic feet in capacity, and its dimensions are 4 feet by 2½ feet by 2 feet. One hundred boxes will sell on the bog for from 15 to 20 shillings, and in the market at from 9 pence to 1 shilling per box, according to quality, demand, and locality. The former is the price at Bundoran, Co. Donegal, and the latter that at Boyle, Co. Roscommon, and at Tuam, Co. Galway. Mr. Hemans has bought fine heavy well-dried black peat in Dublin at 8 shillings per ton. He tried it in locomotives, but found it to be dearer than coal. The weight of a box of peat depends on the degree of dryness of the peat, and from what layer of the bog it has been taken. Its weight, exclusive of that of the box, varies from 2 to 3½ cwt., so that the average weight of 100 boxes might be estimated at about 13 tons.⁷

The authors of the Report on Improved Peat Fuel Manufacture state that on visiting an agricultural exhibition at Munich, in 1872, their attention was "attracted to a *double slane*, intended for cutting two sods of turf at a stroke," which they thought "well suited for raising thin sods."⁸

BROSOWSKY'S PEAT-CUTTING MACHINE.

In North Prussia a peat-cutting machine has been employed, which has the great advantage of being able to cut and raise the peat from a depth of 20 feet or more: by which means, peat, covered by a considerable depth of water, may be utilized without the expense of draining. It consists essentially of a cutter, made like the four sides of a box, but with oblique edges, which is forced down into the peat to the required depth. A spade-like blade is then driven under the cutter by means of levers, whereby the long rectangular prism of peat is cut off at the bottom, and the apparatus is then raised. The prism is afterwards cut up into convenient-sized blocks by means of the blade. It is stated that four hands will cut and lay out to dry from 12,000 to 14,000 peats, or 3100 cubic feet, daily, with the aid of this machine. It is further stated that 1300 of these machines were in operation in Mecklenburg and Pomerania, in about 5 years from its introduction; and that the Mecklenburg moors are now traversed by canals, cut by this machine, which are used for the transport of the peat to market.⁹

⁷ The information was obtained by Mr. Hemans from Mr. E. R. Carrlin, resident engineer, under his direction, on the Sligo and Ballaghaderren Railway, June 1872.

⁸ Report of Commission for Investigation of Improved Peat Fuel Manufacture, 1872.

⁹ Johnson, *Peat and its Uses*, p. 113. Johnson's description is taken from a paper with an illustrative engraving, in Dingler's *Polytechnisches Journal*, 1865, clxxvi. 336. I have read this paper, but have not found the engraving sufficiently clear to induce me to present a woodcut copy of it.

FRENCH PEAT-CUTTING MACHINES.

A machine, having the same object as that of Brosowsky, is stated to have been invented in France in the middle of the last century by Eloi Morel. In the Département de la Somme, in France, two kinds of mechanical peat-cutting machines, differing very much from each other, are in use. The first of these delivers the peat into boats, is worked by two men, and weighs 275 kilogrammes; while the second, which is of much smaller dimensions, delivers the peat upon the ground. Both machines rest upon rails, so as to admit of being moved either to the right, to the left, or backwards. A large well-managed mechanical peat-cutting machine raises from 28,000 to 30,000 peats in 10 hours. At Bray-le-Mareuil, near Abbeville, peat, by means of such machines, is raised from a depth of 9 metres. These machines are in operation at La Ferté-Alais, at Villers-sur-Authie, at Bernay-en-Ponthieu, and in the marshes of Arry, all localities in the Département de la Somme.¹

DREDGING PEAT.

In some localities peat occurs in a more or less mud-like state, and so little coherent that it cannot be extracted by cutting. Thus in bogs in Holland, under the uppermost layer of peat, which is light, spongy, and coherent, is found mud-like peat. The former is cut into large sods or peats, and removed; and the latter is afterwards either dug out with spades, or dredged up by means of bags 18 inches deep, fixed to an iron ring, and made of such material as will permit the water to drain through, while it retains the peat. The mud-peat is turned out on a flat piece of solid ground, surrounded with planks 14 inches wide, set edgewise, and there left to dry to a certain extent; it is then trodden down by men with boards attached to their feet, or stamped with a suitable tool, until it is reduced to less than half its original thickness, that is, to about 6 inches or somewhat less, and becomes so solid that only a slight impression is made upon it by walking over it; and lastly, with the use of a thin sharp spade, it is cut into pieces, which are arranged for air-drying, by placing every successive piece crosswise upon the one below it. By the operation of treading or stamping the cracks caused by desiccation are obliterated, and the peat is made dense and compact. Peat prepared as above described is the dredge-peat (*Baggertorf*) of the Germans, and is stated to be usually of good quality.²

¹ Volume on "Les Primes d'honneur," 1867, p. 92. I am indebted for this extract to my friend A. Ronna.

² Handwörterbuch der reinen und angewandten Chemie, 1861, viii. 937; and Johnson's volume on Peat and its Uses, p. 115.

MECHANICAL TREATMENT OF PEAT.

Common peat, cut from a bog, and air-dried in the usual manner, is so tender and frangible, that it cannot be directly used in furnaces, in which the fuel is required to resist considerable pressure, without breaking into small pieces, and thereby impeding the passage of air through the mass in an injurious degree; and, moreover, for the same reason, it cannot be transported to a distance without considerable loss, owing to the production of much *peat-slack*. But, even, if it had the necessary coherence, it is so bulky, compared with coal, that in some metallurgical operations at least, its use would compel the construction of larger and more costly furnaces. Again, bulky fuel may, in certain cases, occasion not a little inconvenience in transport, as, for example, in that of locomotive engines, where space is an object of importance. There is, however, another objection to ordinary air-dried peat as fuel for furnaces, in which high temperatures are needed, and that is, its comparatively low calorific power, due to the large quantity of hygroscopic water which it retains, even after thorough air-drying, an objection applying likewise to air-dried wood, and, in a less degree, to the kind of coal termed lignite or brown-coal.

The preceding considerations would obviously occur to persons interested in the application of peat as fuel in metallurgical or other manufacturing operations and railways; and they would naturally make attempts to render peat suitable for such purposes. Accordingly various plans to effect that object have from time to time been proposed, and not a few of them tested in practice on a large scale. Before proceeding to describe special methods for the preparation of peat, a few general observations upon the compression of peat may not be out of place.

COMPRESSION OF PEAT (*Pressung des Torfes*, German).

It is possible to squeeze out from fresh wet peat a large proportion of its water; but the facility with which that operation may be effected will be found to vary greatly with the nature of the peat. Thus, spongy and fibrous peat may be easily compressed, practically, without losing anything besides water; whereas the water, which escapes from mud-like peat under compression, is mixed with fine peaty stuff, which makes it difficult, if not impossible, to construct a press with a filtering apparatus such as shall allow clear water to flow out and not become quickly stopped up by fine particles of peat. It has been suggested that neglect to observe this difference in the behaviour of different kinds of peat under compression may tend to account for the diversity of opinion on the economic practicability of the process.³ The following sensible remarks on this subject, by Vogel, may be

³ Vogel, *Der Torf, seine Natur und Bedeutung*, p. 72.

inserted here with advantage. Raw peat, fresh from the bog, contains from 70 to 90 per cent. of water, and is so soft and friable that the handling of it is not only difficult but attended with the production of much waste stuff. On losing 20 or 30 per cent. of its water by compression, it acquires such a degree of consistency as to admit of being easily manipulated, taken to the drying-sheds, and there arranged; so that, if compression to that extent could be easily and cheaply managed, the manufacture of peat on that principle might assuredly be carried on with advantage. But, generally, it has been attempted in experiments on the compression of peat to drive from it as much water as possible, and many persons have expressed their belief that complete desiccation might be so effected, obviously in misapprehension of correct mechanical principles. Peat is extraordinarily tenacious of water,⁴ and at ordinary temperatures only lets the last 20 or 30 per cent. [of that which it loses by atmospheric desiccation] escape with very great difficulty. Moreover, peat is a highly elastic substance, and requires powerful and long-continued compression, after its water has been reduced to 40 per cent., to effect further reduction by only a few units per cent. The cost of pressing is not simply proportionate to the quantity of water expelled, but the progressive increase of the power necessary, and the expenditure of money and time, far more than counterbalance the advantages resulting from the improvement in the quality of the product, even when only moderately powerful compression has been exercised. In good weather, without rain, compressed peat will often dry in a fortnight, whereas raw cut-peat, in the same weather, will require not less than from four to six weeks.⁵ But in rainy weather compressed peat will absorb proportionately more water than raw cut-peat, swelling up and rendering nugatory, either wholly or partially, the effect of compression; and numerous trials have proved that, when compressed peat is exposed to changeable weather, it shows either no advantage or only a very slight one over raw cut-peat with respect to the time requisite for desiccation. When peat is left under cover, not in the open air, to dry spontaneously, the difference in favour of compressed peat is somewhat greater, though never so considerable as to outweigh the increased cost of compression; but when drying by artificial heat, in closed chambers, is resorted to, the superiority of compressed peat is more decided. On drying compressed and still moist peat in that manner, it swells up much, but contracts during subsequent desiccation to nearly its former bulk, and becomes pretty solid and firm, according to the degree of compression to which it had been subjected. If such peat be compared with peat from the same bog which has been pulped by

⁴ "Der Torf hat eine ganz ungemeine Anhänglichkeit an das Wasser."

⁵ Johnson makes an opposite statement. He writes, "Although pressure will squeeze out much water from a saturated, well-ripened peat, the complete

drying of the pressed blocks usually requires as much or more time than that of the unpressed material, on account of the closeness of texture of the surface produced by the pressure."—*Peat and its Uses*, p. 117.

machinery, then moulded and artificially dried, the latter will be found to be not only as hard as the former, but far more homogeneous. Pulped peat is not liable to crumble, while compressed peat shows a tendency to fracture in the direction determined by its original structure. The specific gravity of peat, which has been very strongly compressed, and afterwards artificially dried, is not sensibly greater than that of well-made pulped peat, which has been left to its natural contraction on drying, while the tenacity or resistance to fracture of the latter is much greater.⁶

It has been asserted that, in heating power (*i. e.* not *calorific power*, but *practical* heating effect in burning on the large scale under ordinary conditions), compressed peat is inferior, weight for weight, to the same peat, prepared in the ordinary way, when both contain the same proportion of water; and the reason which has been assigned for this inferiority is a purely mechanical one, namely, the greater compactness of compressed peat, and, as a consequence, its less perviousness to atmospheric air during combustion. No change in the composition of peat is caused by compression, if peat of suitable quality be operated upon, for, with a press of proper construction, nothing is expelled besides water. But in comparative trials of peat, compressed and uncompressed, with respect to heating power, much may depend on the furnace employed for the purpose, for the kind which is suitable for the one may be unsuitable for the other. A powerful chimney draught or artificial blast might be best for compressed and worst for uncompressed peat. Flat-sided and evenly formed bricks of compressed peat may, when thrown whole into a furnace, lie too closely upon one another, and so injuriously obstruct the passage of air through the fire; they may also be too tough to admit of being conveniently broken up into lumps like coal.

CONDENSATION OF PEAT.

Numerous attempts have been made to remove the various defects—as fuel in metallurgical and other operations—which ordinary air-dried peat possesses, and which have been previously specified. The principles involved in these attempts, are the condensation and desiccation of peat by various processes. The methods employed in its condensation may be classified as follow:⁷—

- I. CONDENSATION OF RAW (OR WET) PEAT BY COMPRESSION.
- II. CONDENSATION OF AIR-DRIED PEAT, COLD, BY COMPRESSION.
- III. CONDENSATION OF AIR-DRIED PEAT, HOT, BY COMPRESSION.
- IV. CONDENSATION OF RAW PEAT, BY PULPING, MOULDING, AND AIR-DRYING, OR DRYING BY ARTIFICIAL HEAT, WITH OR WITHOUT COMPRESSION.

⁶ Vogel, *Der Torf, seine Natur und Bedeutung*, pp. 73-75.

⁷ This arrangement is founded on that presented by Johnson in his volume on *Peat and its Uses*.

L—CONDENSATION OF RAW (OR WET) PEAT BY COMPRESSION.

Various presses for the condensation of raw peat have been constructed, from time to time, and tried on a practical scale; but, owing to one cause or other, such as complication of parts, original price, cost of maintenance and working, etc., they have generally proved to be failures in an economical point of view, and have been abandoned. Descriptions of such machines will be found in papers, in journals, in the records of patented inventions, and in volumes which treat exclusively of peat; and of these numerous sources of information the following may be mentioned:—Bromeis, *The Newest Methods of Preparing and Condensing Peat (Die neuesten Methoden der Aufbereitung und Verdichtung des Torfes)*, Berlin, 1859; Dullo, *The Utilization of Peat in Europe (Torfverwerthungen in Europa)*, Berlin, 1861; *Wagner's Jahresbericht* for 1861, vii. 703; Ruttner, *On the Winning and Preparation of Peat (Ueber die Gewinnung und Aufbereitung des Torfes)*, 1860; *Berg- und hüttenmännisches Jahrbuch der k. k. Bergakademien Schemnitz und Leoben* for 1861, xi. 19-78; Vienna, 1862; Vogel, *Peat, its Nature and Application (Der Torf, seine Natur und Bedeutung)*, Brunswick, 1859, pp. 170, with 44 engravings on wood; Johnson, *Peat and its Uses* (New York, 1866, pp. 168, with 25 engravings on wood); and the *Abridgments of Specifications relating to the Preparation and Combustion of Fuel* (London, 1867, pp. 1407). It is probable that the construction of machines for making bricks and artificial fuel from coal-slack might also be studied with advantage by persons interested in the compression of peat.

EARLIEST PEAT PRESSES.

The earliest kind of machine for compressing raw peat, that is, peat as it comes wet from the turbary, was very simple, and consisted of a rectangular frame fitted with a flat piston, which might be strongly depressed by a lever or otherwise, provision being made for the escape of water from the peat during its compression. A patent was granted in 1839 to Lord Willoughby de Eresby for a machine constructed on that principle, which had two frames so connected that as one was withdrawn the other came under the press, and each was fixed on a separate axis, so that after leaving the press it might be turned round and made to discharge its contents: in the piston or "pressing plate" were several holes filled with wood, with the grain vertical, so that water might percolate through and flow away from the peat when subjected to pressure.⁸ It is reported that Pernitzsch compressed peat in Saxony in a similar manner so long ago as 1821.⁹

SCHAFHÄUTL'S PRESS WITH ROTARY MOTION. — The first peat-compressing machine with rotary motion is said to have been invented by

⁸ *Abridgments of Specifications relating to the Preparation and Combustion of Fuel.* Date of the patent, July 20, 1839, No. 8160.

⁹ Johnson, *Peat and its Uses*, p. 116.

Schafhäutl, but soon given up, on account of certain mechanical difficulties which were found to occur in course of working.¹ Compression was effected by placing the peat in frames fixed on an endless chain passing between a pair of rolls, set a certain distance apart, grooved rectangularly in the direction of their axes, which were horizontal and in the same vertical plane. Engravings of this press are given in Vogel's volume.

COMPRESSION BY ROLLING.

It is reported that at Neustadt, in Hanover, in 1860, loose-textured fibrous peat was passed through iron rolls of the ordinary construction, and reduced to one-third of its original bulk, with a view to its use in metallurgical operations. The peat thus condensed burned more regularly, yielded coherent coke, and better resisted carriage. Before rolling, the peat was cut into sods of uniform size.² Kraut, in 1857, found that air-dried compressed peat, manufactured at the Neustadt Smelting-works, yielded, when examined in November, 11·15 per cent. of water, 2·4 of ash, and 36·4 of charcoal or coke, and that in February the air-dried peat contained 10·31 per cent. of water, 53·47 of carbon, 5·27 of hydrogen, 27·97 of oxygen (inclusive of nitrogen), and 2·98 of ash.³

MANNHARDT AND KOCH'S PRESS.

A singular machine, which is the invention of Mannhardt and Koch, and is reported to have been applied on a large scale at Schleisheim, near Munich, deserves notice.⁴ The specification of the English patent is illustrated with a large mechanical drawing, which will sufficiently indicate the complicated and costly nature of this press. It is stated that such a press of full size was exhibited in Dublin in 1859, and obtained the approval of Sir Robert Kane.⁵ The object of this machine is declared by the inventors to be the speedy preparation of peat for firing, independently of the state of the weather, in the following manner.

The principal feature of the invention consists in the use of a pair of large hollow horizontal rolls, covered with cloth to serve as a filter, and revolving once in about seven minutes. No dimensions are prescribed in the specification, but the diameter of the rolls in the presses which have been actually made is about 15 feet and the width 6½ feet. On the circumference of the rolls, ribs of hoop-iron are fixed obliquely about 1 inch apart, which support drilled iron plates surrounded by an endless band of cloth. The wet peat is torn to pieces and put into two

¹ Vogel, *Der Torf*, etc., p. 80.

² Johnson, *op. cit.* p. 119.

³ Wagner's *Jahresbericht*, 1858, iv. 621.

⁴ It was patented in this country in 1858, June 2, No. 1235. See Vogel, *op. cit.*

p. 81, and Johnson, *op. cit.* p. 117. See also the specification of a patent granted to Theodor Erich, and dated Sept. 1, 1863, No. 2163.

⁵ *Berg- und hüttenmännische Zeitung*, 1859, xviii. 880.

hoppers, one over each roll, whence it is drawn by rake-rollers and laid equally upon the cloths, moving with the rollers; but in its course to the large rolls it passes through a series of three small rolls fixed above each large roll, whereby it is deprived of most of its water. There are thus two streams of peat, descending from the two hoppers and passing first through a pair of small rolls, then through a pair of spiked rolls, and lastly through the two large rolls, by which the remaining water is pressed through the filter-cloth into the interior of those rolls. The peat now forms a compact sheet, which is conveyed by a filter-cloth working on rollers, first to a knife-like cutting apparatus, which divides it transversely, and then by another endless band of cloth to circular cutters, which divide it longitudinally into blocks of the required dimensions. The blocks thus fashioned, which are about 12 inches long, 5 wide, and $1\frac{1}{2}$ thick, and weigh about $1\frac{1}{2}$ lb. each, are carried away to be dried. The peat is thus freed from water to such an extent that its further desiccation may be effected in favourable weather in the course of a few days under covered airy sheds, or in unfavourable weather by artificial heat in suitable apparatus. Goat's hair has been found by experience to be the best material for the filter-cloth, yet, even when this material is used, it becomes choked by fine particles, and it is necessary on this account to expose it at each revolution to jets of water impinging upon it at high pressure. The expressed water is only slightly turbid from suspended particles. About 100,000 peats are produced in 24 hours. The cost of the machine is said to be about £1600, and a steam-engine of 12 horse-power suffices to drive it.

II.—CONDENSATION OF AIR-DRIED PEAT, COLD, BY COMPRESSION.*

This process was in operation in Lithuania in 1859, but how long previously is not stated. The turbary is drained and freed from its superficial covering of moss, sward, and roots, after which it is ploughed with an extremely simple spade-plough (*Spatenpflug*) to the depth of 8 or 10 inches, in furrows 2 inches wide, after which wooden harrows are passed frequently over it, in order to break up and promote the drying of the turned-up peat. It is known that the peat is sufficiently dry for compression when, by rolling it up in the hand, a ball is produced so tender as to fall to powder if dropped upon the ground. In this state the peat is rammed into moulds by stamps weighing 2 cwt. each, and thereby made into blocks sufficiently firm to admit of being cut by a saw or hatchet without splintering; the blocks

* The following information concerning this process has been derived from a paper entitled, "Die in Litthauen gewöhnliche Gewinnung und Comprimirung des Torfes." By Bergmeister W. Leo. Allgemeine Berg- und hüttenmännische Zeitung, edited by Dr. Carl Hartmann, Quedlinburg, 1859, i. 253. See specification of a patent granted to J. W. Rogers, and

dated June 1, 1848, No. 12,169. Artificially dried peat is compressed in moulds, by means of plungers, a perforated metal plate forming the bottom of each mould. Also the specification of a patent granted to C. Wye Williams, and dated July 26, 1838, No. 7744. Air-dried peat is compressed in a mould, and the blocks are afterwards further dried by artificial heat.

are deep-brown, glazed, and require no further desiccation. Only the best earthy peat is used for compression, and that pretty closely approximates to earthy brown-coal in its nature; and such coal is made into solid blocks in the same manner as the peat. By compression the peat is reduced to $\frac{2}{3}$ of its original bulk. There is no loss of peat from waste in this process, and the manufacture may be carried on without interruption during winter, provided a large enough store of prepared peat has been accumulated in the summer preceding. It is stated that a cubic foot of the compressed peat weighs 80 lbs., and that the cost of production, inclusive of plant, etc., amounts to 4 Silber-groschen per Centner, or about 8 shillings per ton (1 Centner = 113·426 lbs. and 1 Silber-groschen = 1·17 penny). The ramming is so simple an operation that women and youths can manage it. The mould is of cast-iron let into a wooden frame, and resembles in form such as is commonly used for making slop-bricks. The stamp is also of cast-iron, encased in wood with leather packing interposed, and protrudes about 5 inches beyond the wooden frame; it works between two upright guide-rods, and the machine seems to be similar in construction to those which are so extensively used in Birmingham for stamping metal. This compressed peat is reported to be specially suitable for carbonization, and to yield "a very fine solid charcoal."

III.—CONDENSATION OF AIR-DRIED PEAT, HOT, BY COMPRESSION.

EXTER'S PROCESS.

This process, it is asserted, has been brought to the "highest degree of perfection" in a large and costly establishment situate between Munich and Augsburg, where there is an extensive range of peaty moorland known as "Haspelmoor."⁷ The organic matter of this peat is stated to have the following composition per cent.:⁸—

| | |
|---------------------------|--------|
| Carbon | 58·93 |
| Hydrogen | 5·72 |
| Oxygen and nitrogen | 35·35 |
| | <hr/> |
| | 100·00 |

The peat varies in thickness from 15 to 40 feet (Bavarian); and, as it rests upon a watershed, it admits of being easily drained by trenching. The moor is worked in rectangular plots, 3000 feet long and 1500 broad, which are pared as usual and then flattened so that

⁷ Several descriptions of this establishment have been published; but the following information concerning it has been chiefly taken from a paper in the *Berg- und hüttenmännisches Jahrbuch der k. k. Bergakademien Schemnitz und Leoben* for 1861, xi. 19, entitled, *Ueber die Gewinnung und Aufbereitung des Torfea, als Bericht über die im Jahre 1860 nach Salzburg und*

Bayern unternommene Reise von Joseph Ruttner von Grünberg, k. k. Unterverweser zu Mariazell, p. 63. See the specification of a patent granted to Charles Hodgson, and dated Dec. 10, 1858, No. 2837. It is similar in the main to Exter's process.

⁸ Kraut, *Wagner's Jahresbericht*, 1858, iv. 620.

water may drain from the centre towards each of the four sides of a plot into the surrounding trenches, care being taken that no depressions are left in which rain-water might collect and form puddles. The surface is ploughed to the depth of 2 or 3 inches by steam-ploughs of peculiar construction, and the peat so turned up is disintegrated by raking it over two or three times with wooden rakes such as are used in hay-making. In sunny and windy weather the peat becomes so dry that, after having been turned over two or three times, in the course of two or three hours, it will no longer cohere by pressure, though it still retains from 30 to 40 per cent. of water; and, when sufficiently dry, it is heaped together in small stacks, to be ready for conveyance to magazines near the works. The raw peat is compact and "fat" (*Specktorf*), and, when air-dried, is elastic and friable; and as it is much intermixed with roots, it is not good for cutting. The peat is put into a bolting-machine, formed of wire-gauze, somewhat inclined, open at top and bottom, octagonal in cross-section, and which during rotation is subjected to concussion in the usual manner. The fine peat drops through, while the coarse, which consists of lumps and pieces of roots, is carried forwards and falls out at the lower end. The latter is used as fuel for raising steam, and the former is heated to 100° C. and pressed, while hot, into blocks. The drying apparatus, according to one account, is a rectangular chamber of mason-work, divided longitudinally into six equal and similar compartments, the floors of which are hollow and made of sheet-iron, and are heated by steam circulating through them. But in another account the drying apparatus is described as consisting of "large horizontal sheet-iron cylinders open above, in which the small peat is moved forwards by means of an Archimedean screw (*Schnecke*), and so turned over constantly. These cylinders and the entire chamber containing them are heated by hot air, the heating of which is in part effected by waste steam."* The fine peat is put into the top compartment, and is thence carried in succession through the other compartments by means of sheet-iron screws, resembling in form those of an Archimedean pump, geared so as to revolve in an opposite direction in every successive compartment. Hot air is also caused to circulate under the bottom of the lowest compartment and thence upwards along the sides over the roof of the top compartment. The press consists essentially of a box, open at both ends, of the same form and area in cross-section as the largest side of a peat-block, and is fitted with a piston which is moved horizontally by means of an eccentric. When the piston is withdrawn to the fullest extent, hot peat drops into a channel open at the top between the piston, when in that position, and the mouth of the box, and is pushed into the box and compressed by the forward movement of the piston, block after block being quickly formed, and thrust out at the opposite end of the box. The box is long enough to contain several finished blocks at the same time; and there is a contrivance for contracting the box towards the outlet end, so that at

* Vogel, *Der Torf, seine Natur und Bedeutung*, p. 97.

starting sufficient resistance may be offered to the passage of the peat to effect its compression into a solid block. When once a few solid blocks have been fashioned, the contraction may be removed, as the resistance offered by them, owing to friction, suffices for all the rest. The form of a peat-block is like that of a thin brick with the angles rounded off; and the dimensions are as follow: $8\frac{1}{2}$ inches long, 3 inches wide, and nearly 1 inch thick (1 inch Bavarian = 1.0371 inch English). While in the press, the block of peat has its large side vertical and its long axis horizontal and at right angles to the piston-rod. The blocks, one by one, drop hot from the press into trucks, and are taken away. A single press will produce 7920 blocks in an hour. The peat is contracted by this process to $\frac{1}{4}$ or $\frac{1}{5}$ of its original bulk; its specific gravity after compression is 1.2 , and the mean weight of a cubic foot is 70 lbs.; it contains from 10 to 12 per cent. of water and from 7 to 8 per cent. of ash; the blocks are very firm, very smooth on the surface, and the narrow sides acquire by friction against the internal surface of the press-box a shining black coat; they are used for locomotives chiefly on the Nuremberg railway. According to Vogel, a cubic foot of this peat weighs 64 lbs.; its specific gravity is 1.52 ; it exceeds not only all kinds of prepared peat in that respect, but even coal; it is five or six times heavier than cut-peat from the same turbarry, and contains from 15 to 18 per cent. of water.¹ How these discordant statements regarding absolute weights and specific gravities are to be explained, it must be left to the reader to conjecture: the cubic foot of a substance of which the specific gravity is 1.52 should weigh about 95 lbs. instead of 64; but every one knows that one of the commonest typographical errors consists in setting up a 6 inverted, which looks like a 9, and *vice versa*. Bromeis supposed that by heating the peat to the degree stated, only 100° C., tarry matter was developed, and caused the agglutination of the particles into a coherent mass; but this supposition is opposed to the fact, confirmed by Vogel in his numerous observations on the distillation of peat, namely, that tarry vapour only begins to be evolved at a much higher temperature than 100° C. Vogel thinks that the cohesion is wholly due to pressure, and is precisely of the same kind as that communicated by pressure to particles of dry clay, or that by which he has seen sheets of dry pasteboard made to adhere firmly to each other by pressing them strongly together, without the use of any binding material such as paste; and that the action of heat is merely to soften the particles of peat and thereby to facilitate and promote their cohering together, though heat is not absolutely necessary, as the same result may be obtained by powerful pressure alone.² Johnson considers that the effect of heating in Exter's process is to remove the air ordinarily adhering to the fibres and particles, and to soften and render more plastic those fibres, in order that pressure may bring them into more intimate contact; and he states, that although the peat is considerably dried in the ovens, yet on leaving them it is so moist as

¹ Der Torf, etc., p. 98.

² Idem, p. 98.

to bedew the hand when immersed in it, so that it is in fact steamed by the vaporization of its own water. The notion that the heat developes bituminous matters or melts resins pre-existing in the peat, and that these cement the particles together, does not accord with the fact that the peat, thus condensed, flakes to pieces by a short immersion in water.³ This conclusion, however, supposes that the proportion of those agglutinating substances which would suffice to cause cohesion would also prevent disintegration in water, but this by no means follows as a necessary consequence. The cost of production (*Erzeugungspreis*) is reported, though not authoritatively, to be 16 or 17 Kreuzer per Centner, or somewhat under 9s. per ton.⁴ The cost of the compressed peat manufactured by this process is stated to have been, in 1871, about 12s. per ton, exclusive of interest on outlay, wear and tear of plant, etc.⁵ The advantages of Exter's method have been stated to be as follow: thorough desiccation of the peat when in its dust-like state, whereby its calorific power is greatly increased,—the smoothness of the surface of the finished blocks, whereby they are protected from the action of moisture,—the utilization of the whole of the peat gotten, as the finest particles are worked up,—the remarkably easy, rapid, and favourable method of getting the peat in large quantities, so that the manufacture may be carried on during winter as well as summer,—and saving of expense, by lessening the labour in handling and carrying peat in the state in which it comes wet from the bog. Compressed Haspelmoor peat in the air-dried state was found in November to yield 16·74 per cent. of water, 6·9 of ash, and 36·3 of coke; and in the same state in February it was found to contain 15·50 per cent. of water, 44·82 of carbon, 4·35 of hydrogen, 26·90 of oxygen (inclusive of nitrogen), and 8·43 of ash.⁶ Exter's process, it is stated, has been adopted with some modifications at Kolbermoor, near Munich; at Miskolz, in Hungary; and at the Neustadt Smelting-works, in Hanover; but at the last-named place it was abandoned, because it could only be applied to the better kinds of peat, and the expense, there, was so great that the product could not compete with other fuel in the Hanoverian market.⁷

MODIFICATION OF EXTER'S PROCESS.—Johnson reports that Dr. Elsberg, of New York City, has invented a modification of Exter's method, "which appears to be of great importance," though we are not informed whether it had advanced beyond the experimental stage. The air-dried peat is made moist and warm by exposure to "hot steam" before it passes into the press; but this product will assuredly contain more water than that which Exter converts into blocks.⁸

³ Johnson, *Peat and its Uses*, p. 126.

⁴ Vogel, *op. cit.* p. 100.

⁵ Report of Commission for Investigation of Improved Peat Fuel Manufacture, 1872. Dublin, 1873.

⁶ Kraut, *Wagner's Jahresbericht*, 1858, iv. 620.

⁷ Johnson, *Peat and its Uses*, p. 123.

⁸ *Idem*, p. 125.

IV.—CONDENSATION OF RAW PEAT, BY PULPING, MOULDING, AND AIR-DRYING, OR DRYING BY ARTIFICIAL HEAT, WITH OR WITHOUT COMPRESSION.

CHALLETON'S PROCESS.

Works for carrying out this process were erected, in 1854, by M. Challeton at Montauger, near Corbeil (Seine-et-Oise).⁹ The peat, which is extracted by cutting or dredging, is conveyed to the works in boats, by canals in the turbary, and put into a tank lined with boards and deepening at the bottom towards the centre. The peat is thence raised by a chain of buckets to the hopper of a dividing apparatus, which consists of a series of cylinders 4 feet long, but differing in diameter, fitted with knives 4 inches long and $1\frac{1}{2}$ inch thick. These cylinders rotate pretty quickly, and tear up the peat, which is next ground in a mill with conical surfaces, like a common coffee-mill, after the addition of sufficient water. Between the cylinders and the conical mill is a sieve with brushing apparatus,¹ which retains filaments and grosser particles, and allows the rest of the peat, now in a mud-like state, to pass through. The muddy liquid falls into tanks, and is stirred up by the rotation therein of a shaft carrying arms, while a stream of water keeps flowing in at the bottom, and the muddy mixture is removed to a certain depth from the surface by a chain of buckets, and poured into a wooden trough communicating with filtering tanks. During the agitation of the mass, heavy stuff, such as sand, etc., previously existing in the peat speedily subsides, and is thrown away. Steam is the motive power, and the fuel used is raw peat. The filtering tanks are rectangular, and formed by setting planks edgewise on the ground and covering the bottom of the included space either with matting or with a layer of reeds or flags, so that water may filter through; they have each a superficial area of about 150 square feet, and their depth, which is from 1 to 2 feet, is calculated so that after desiccation the deposit in each may have the same thickness as that of the peat-brick required; there are about 800 of such filtering tanks. In the course of 4 or 5 hours² most of the water will have drained away and the peat have acquired a felt-like consistency; it is then to be cut, or rather indented,

⁹ This process was patented in this country. The specification is dated April 18, 1854, No. 897. The following account is a pretty close translation of an article in the French translation of the 1st edition of this work (i. 393); but a few details have been derived from Johnson (*op. cit.* p. 128), who quotes from the report of a commission deputed by the Agricultural Society of Holstein and by the Hanoverian government to visit Challeton's peat-works in 1854; which report was published in Henneberg's *Journal für Landwirthschaft*, 1858, pp. 42 and 83. See also the provisional specification of

a patent granted to William Clark, May 21, 1858, No. 1138.

¹ In Johnson's description it is stated that the torn-up peat "passes into a chamber where the fine parts are separated from unbroken roots and fibres by revolving brushes, which force the former through small holes in the walls of the chamber, while the latter are swept out through a larger passage."—*Op. cit.* p. 129.

² Johnson says, "In a few days the water either filters away into the ground or evaporates, so that a soft stratum of peat about 3 inches in thickness remains."—*Op. cit.* p. 129.

all over its surface by means of a frame, divided by thin partitions into 50 similar compartments, each of the same length and width as a wet peat-brick. As desiccation proceeds, the layer of peat separates into bricks in the direction of the lines so impressed; and in favourable weather, after the lapse of a few days these bricks will admit of being handled and arranged in the usual manner for air-drying. After four months' exposure to the open air, the peat will still retain as much as 16 per cent. of water. According to MM. Petitgand and Ronna, the hope that this process would yield compact, hard, and homogeneous peat has not been fulfilled; but, on the other hand, the product has the advantage of not containing much earthy impurity. The specific gravity of the bricks is about 1.22 and sometimes as high as 1.50; and organic structure is but little visible in them. The raw or fresh peat produces from 14 to 15 per cent. of its weight of bricks; the proportion of ash is reduced to $\frac{1}{3}$ of its original amount. With regard to manufacture, it is stated that, owing to the little plasticity and coherence of the mass out of which the bricks are cut, the waste on drying is considerable; that against the advantage of kneading the peat-pulp with water may be set the inconvenience of moving so much water as is required in that operation; that the cleaning of the peat causes much waste; and that as desiccation depends upon atmospheric temperature and the state of the weather in other respects, there is risk of losing both time and interest on the capital invested. The opinion has been expressed that Challeton's works were not remunerative, and it is reported that several works on his plan have been established in Germany with the like result.³

The peat-works of M. Roy, at St.-Jean, Lake of Bienné, near Neuchâtel, in Switzerland, and of M. Hebert, at Rheims, are reported by Petitgand and Ronna to be nearly identical with those at Montauger; but according to Vogel, Roy's process is similar in principle but not in manipulation to Challeton's.⁴ Vogel states that the cost of manufacturing peat at Montauger, exclusive of rent and interest of capital in plant, is about 14 Kreuzer per Centner, and that at Roy's works it is about 18 Kreuzer per Centner, or from 12 to 13 francs per 1000 kilogrammes (in round numbers, from 9s. 5d. to 10s. 2d. per ton). Assuming the Bavarian Centner to be here meant, which is equal to 123.457 lbs. avoirdupois, the cost is roundly about 8s. 4d. per ton at the former, and 10s. 10d. at the latter works, but whether this is the total cost does not certainly appear.⁵ Kraut found in 1857 that the air-dried prepared peat of Montauger yielded, when examined in November, 18.85 per cent. of water, 11.35 of ash, and 42.8 of charcoal or coke, and that in February the air-dried peat contained 17.11 per cent. of water, 44.77 of carbon, 4.01 of hydrogen, 23.67 of oxygen (inclusive of nitrogen), and 10.44 of ash.⁶

³ Johnson, *Peat and its Uses*, p. 130.

⁴ *Der Torf, seine Natur und Bedeutung*, p. 88.

⁵ *Idem*, p. 93.

⁶ Wagner's *Jahresbericht*, 1858, iv. 621.

MODIFICATION OF CHALLETON'S PROCESS AT LANGENBERG.⁷—The peat occurs in marshes traversed by the river Oder in its course from Stettin to the sea, and in the vicinity of this town is Langenberg, where the works are situate. Steam-dredges are used to raise the peat, which is of mud- or slime-like consistency, and flows directly into a mill of the following construction. There is a circular wooden tub 10 feet in diameter, 2 feet deep, and 2 inches thick, within which is fixed concentrically a circular cage-like sieve 8 feet in diameter and 2 feet deep, made of $\frac{3}{4}$ -inch round iron. In the axis of this apparatus is a shaft, which rotates about 20 times per minute, to which are attached four radial arms, each carrying at its free end a strong vertical brush in actual contact with the sieve. The peat-mud is put within the sieve, so that any roots and coarse fibres may be retained there, while the fine peaty substance passes through into the annular space between the sieve and the wooden tub. There were four such tubs in use at Langenberg. During this operation the addition of water is always required. The peat-mud so prepared flows into another tub similar to the first, but placed at a lower level, in which is a pair of wooden mill-stones 8 feet 6 inches in diameter, if such an expression as *mill-stones* be permissible under the circumstances; the fixed one at the bottom is 8 inches thick, and the top one or runner 21 inches thick; the grinding faces are deeply grooved in the usual directions, and work with the grain of the wood in one stone set cross-wise to that in the other. The eye or feed-hole in the runner, which receives the peat-mud from the upper tub, is 4 feet 8 inches wide. The outflow channel from the stones is closed by a valve, by means of which the level of the liquid outside the runner can be altered at will, the runner consequently made lighter or heavier, or even actually to float, and the fineness of the grinding regulated. Moreover, the runner, with the deep grooves on its grinding face, acts like a centrifugal pump, when, in revolving, the feed-hole is kept constantly empty and the slime is driven outwards so as to overflow the rim of the tub. It should be stated that all peat cannot be treated in the manner described, such, for example, as occurs in the low-lying marshes of the Oder, usually about 7 feet below the surface, which is of a reedy origin, and not unlike half-decayed straw in appearance.

The ground thin peat-mud from the four mills runs into a channel 5 feet wide, and inclined at the bottom, from the deepest part of which it is raised by a centrifugal pump, 30 inches in diameter, and making 220 revolutions per minute, into another channel 18 feet above the former; and from this it is distributed into reservoirs formed on levelled and higher ground, each of which is enclosed on three sides by banks of earth and on the fourth by planks set edgewise, and is

⁷ The following information has been derived from a paper by C. Wassersieher, engineer, in *Dingler's Polytechnisches Journal* (1864, clxiv. 64–112), entitled

“Die Torfmoore des unteren Oberthals von Stettin abwärts und deren Austorfung, mit besonderer Besprechung der Torffabrik zu Langenberg.”

drained by ditches on the outside. These reservoirs are filled to the depth of 20 or 22 inches with peat-mud, and the area covered daily is about 3830 square metres, or 4580 square yards, somewhat less than an acre. In the course of from 4 to 8 days, according to the weather, the mud begins to crack over the surface, when the cracks are effaced and the mass solidified by men walking to and fro over it with boards 10 inches long and 5 wide attached to their feet. After the further lapse of 6 or 8 days the bed of peat is cut by peat-cutting knives in the direction of lines previously made by passing over its surface a rake, with teeth $3\frac{1}{2}$ inches apart. After 4 or 6 more days the peat is cut crosswise into blocks, which are then ready for drying. The specific gravity of the peat varies from 0.73 to 0.9; and the interstitial space is estimated at about 46 per cent. About 125,000 Centner or 5753.5 English tons of peat are produced in 60 days of 12 working hours each, the Centner consisting of 100 lbs. Prussian or 103.111 lbs. avoirdupois. The peat is stated to be chiefly used for reheating furnaces on the Siemens' regenerative principle in the manufacture of iron; and the blocks are from 6 to 8 inches long and from 2 to $2\frac{3}{4}$ inches square in cross-section. The price on the spot, free on boats ready for transport, is $3\frac{1}{4}$ Silbergroschen, or 3.96 English pence, per Centner (30 Sgr. being equal to 35.78 English pence), or roundly between 7s. and 8s. per ton.

MODIFICATION OF CHALLETON'S PROCESS IN THE UNITED STATES.—According to Johnson, Mr. S. Roberts, of Pekin, New York, was engaged in 1865 in experimenting on the preparation of peat by a method essentially the same in principle as that of Challeton; but up to April 1866 it was not ascertained whether the results would prove satisfactory in a commercial point of view.⁸

PREPARATION OF PEAT AT STALTACH, IN BAVARIA.

(WEBER'S PROCESS.)

It is reported that the mechanical preparation of peat for fuel has been carried out, with great success in every respect, at the works of Maffei and Weber, situate at Staltach, at the southern end of the Lake of Starnberg, in Bavaria; and a full account of the process was published by Vogel in 1859, from his own personal observation,¹ from which the following information has been mainly derived. The supply of peat is obtained from a neighbouring turbary, in which the average thickness of the peat may be estimated at 20 feet (1 Bavarian foot = 11.42 inches English). The peat is light and fibrous; in the upper part of the bog it is light-brown, while in the lower part it is dark-brown, and intermixed with roots, which make

⁸ Peat and its Uses, p. 132.

¹ Dingler's Polytechnisches Journal, 1859, clii. 272-286. Berg- und hütten-

männisches Jahrbuch for 1861, xi. 72-78. Published 1862. The latter description is illustrated with sketches.

the cutting of it difficult; and it contains a very small quantity of inorganic matter, yielding, after drying at 100° C., not more than 1·8 per cent. of ash.²

The peat is cut out in pieces of about a cubic foot in volume, worked into pulp, but not into slime, moulded without compression into brick-shaped pieces or bricks, as they are termed, and dried under cover, first by simple exposure to the air, but afterwards by artificial heat. Solely by gradual contraction on drying, the peat acquires the aspect of "compressed peat," and is not inferior to it either in tenacity or compactness. Vogel maintains that peat so prepared is far superior in quality to every other kind of manufactured peat, especially to the hard-pressed (*hartgepresste*).

Three men with the use of heavy spades will cut on the average 200 cubic feet per hour, or about 2500 cubic feet per day, picking out at the same time all the larger roots of pine (*Pinus Pumilio*), which frequently occur, and which increase the labour in cutting. These roots are met with in all the Upper Bavarian highland turbaries (*Hochmoor*). The peat is reduced to homogeneous pulp in a mill, consisting of a vertical sheet-iron cylinder 4 feet high and 3 feet in diameter, open at the top, in which rotates a vertical shaft carrying eight blades. The blades are curved, triangular in cross-section, and sharp at the convex edges, for the purpose of cutting the peat. Peat is put in at the top of the cylinder, and pulp escapes from the bottom at the rate of about 400 cubic feet per hour, dropping into a truck underneath. The mill works 12 hours daily, and delivers from 4000 to 5000 cubic feet of pulp. When the peat is too dry for pulping, water is added at intervals. The mill is driven by a 10 horse-power steam-engine, usually working half-power with a pressure of three atmospheres. Pulping in this process is effected by cutting, and not by rubbing, as in Challeton's machine, which would be unsuitable for the Staltach peat on account of its fibrous nature.

The pulp is either moulded direct, or treated in the manner described further on. In the first method the pulp is moulded in wooden frames, open at top and bottom, and divided by partitions into seven similar and equal compartments. The moulds are laid on the drying-ground, filled by hand, just as in making common bricks, and then raised, leaving the peats on the ground. After a few days they are turned over and again left to dry, having become sufficiently firm to admit of being handled without fracturing.³

In the second mode of treatment the pulp is put into pits, provided with drains, the largest holding more than 12,000 cubic feet, and there left until it has lost 20 or 25 per cent. of its water and about 15 per

² It has been found by boring in certain parts of this turbarie that below the peat, at a depth of 22 feet, is a bed of blue clay only a few inches thick, below which peat again is met with; and when the clay was pierced, combustible gas escaped in considerable quantity and with toler-

able force, on ignition flaming up to the height of 6 or 8 feet.

³ See J. Ruttner's paper, above referred to, entitled "Ueber die Gewinnung und Aufbereitung des Torfes," in the *Berg- und hüttenmännisches Jahrbuch*, 1862, xi. 19 *et seq.*

cent. in bulk, which, in favourable weather, happens in the course of a few weeks. The peat is cut out of these pits when it has acquired the proper consistency, in pieces of the required dimensions, by means of an ordinary peat-cutting tool (*Stecheisen*).

The peats are arranged, with spaces between them, under sheds, on frames, in stages one above another, 18 inches apart, and left to air-dry until they become firm enough to be removed and set up, which in good weather in summer requires from 8 to 14 days, but in bad weather it may be a month. The peat is now either stacked in heaps and left during several months, until it has lost about 75 per cent. out of the 90 per cent. of water which it contained when in the bog, or it is conveyed to the drying-house and dried by artificial heat. For 200,000 newly moulded or raw peats, 17 inches (1 Bavarian inch = 0.951 English inch) long, $7\frac{1}{4}$ broad, and $5\frac{1}{2}$ thick, and weighing 18 lbs. each, an area of 50,000 square feet is necessary, that is, four peats to a square foot. Peats of those dimensions, after proper air-drying, weigh only 3 lbs. each. The drying should proceed gradually and as regularly as possible, for otherwise the peats may be distorted, more or less cracked, and deteriorated as fuel. If peat in the wet state, immediately after the moulding, were taken to the drying-house and dried there by artificial heat, it would be much less compact and dense, and have a lower specific gravity than that which is artificially desiccated after having been slowly air-dried. The specific gravity of Staltach peat cut in the usual way at a depth of from 3 to 5 feet, and as perfectly air-dried as possible, is from 0.23 to 0.24.

Although the peats by slow air-drying become outwardly pretty solid, yet inwardly they continue somewhat soft and moist; and hence the final desiccation by artificial heat may be regarded not only as an essential, but as the most important, part of the system. This desiccation is effected in a large massive building, 126 feet long and 46 feet wide, by means of currents of air heated to from about 56° C. to 62.5° C. The air is heated by four flues 12 inches square in section, of the same dimensions throughout, and extending from end to end of the drying-house. These flues are made of mason-work to the length of 60 feet from the fireplace, and beyond that distance of sheet-iron, terminating in chimneys of the same material, 12 inches in diameter. Each flue is contained within another rectangular flue of mason-work; the inner surface of the outer flue being throughout 2 inches distant from the outer surface of the inner flue. Along the top of the outer flue are holes 10 or 12 inches apart, from which hot air escapes, while cold air is conducted from the outside of the building through pipes communicating with holes in the bottom of the outer flue. Outlet is provided for the heated air charged with vapour through forty chimneys, made of zinc, 9 inches in diameter, 6 feet apart, and about 20 feet high, which commence at a height of 3 feet from the floor and pass through the roof. At the height of 5 feet above the top of the outer flues are wooden frames, on which the peats are arranged. The fuel used for firing is peat in small pieces, the waste peat—or, as it might be termed, peat-slack—and roots. Such a drying-house as that having

the dimensions above stated will hold 300,000 peats; and it may be filled in two days and emptied in one, twenty labourers, inclusive of women and children, performing that work. Drying is completed in from 8 to 12 days, according to the moistness of the peat; and quite fresh wet peat requires 14 days. When the peat comes pretty well air-dried into the drying-house, it softens when the temperature increases, and begins and continues to swell until it is heated throughout to the same degree as the house itself, after which it rapidly contracts in bulk, and at last acquires a hardness and solidity not exceeded in peat prepared by any other method. It is hardly possible to break a block of this peat without the exercise of considerable force; a cut surface of it appears as if polished; it presents even in the innermost part no visible trace of moisture; it almost resembles horn in outward appearance, as well as in the sound which it emits when struck; it will bear the roughest handling without injury, so as to admit of being loaded and carried without waste; and in burning it is said to produce a pure, bright, persistent flame as well as an enduring, strong red-heat. In this state its specific gravity is 0.65, and it retains 12 per cent. of hygroscopic water; and a single peat now measures $11\frac{1}{4}$ inches in length, $3\frac{1}{4}$ in width, and $2\frac{3}{4}$ in thickness, and weighs 2 lbs., whereas the same peat in its raw state measured 17 inches in length, $7\frac{1}{2}$ in width, and $5\frac{1}{2}$ in thickness, and weighed from 18 to $19\frac{1}{2}$ lbs. The weight of a cubic foot of the dry marketable peat may be estimated at from 34 to 35 lbs.

It is asserted that it is not desirable to reduce the proportion of moisture below 10 or 12 per cent., because not only would further desiccation be expensive, but useless; as the peat would, afterwards on long exposure, absorb water from the atmosphere equal in quantity to that driven off by such extra desiccation. Vogel found that the hygroscopic water in a block of prepared Saltach peat was only increased to 15 per cent. by lying in a moist cellar during several days, whereas ordinary cut peat, after exposure to the same conditions, yielded from 25 to 30 per cent.

With regard to rate of production and cost of manufacture, Vogel gives the following details. On an average, three men will raise in one day from the turbary 2400 cubic feet of raw peat, and the pulping-mill will work up at least twice that amount. Estimating the raw peat at 4500 cubic feet per day, this quantity will yield about 4300 cubic feet of peat-pulp or 10,750 peats, or 322 Centner of air-dried, or 215 Centner of artificially dried peat (1 Centner = 100 Bavarian lbs. = 123.457 lbs. avoirdupois). In moulding, two men will produce, by the first of the two methods previously mentioned, 2000 peats, and by the second method twice that number; the average daily number per man may be taken at 1500 peats. The cost is reckoned as follows :—

COST OF GETTING AND MANUFACTURING PEAT AT STALTACH.

60 Kreuzer = 1 florin = 2 shillings or 1 florin English.

1 Kreuzer = 1·60 farthing English = 0·4 penny.

| | Per Centner. |
|-------------------------------------|-------------------------------|
| Cost of the air-dried peat | 7·80 to 8·00 Kr. |
| " " artificial drying | 2·66 .. 2·66 " |
| Cost of the artificially dried peat | 10·46 to 10·66 Kr. |
| Say..... | 10·5 Kr., or very nearly 4½d. |

Vogel estimates the cost of the same kind of peat cut in the usual way, and then air-dried, at 13·5 Kr., or rather more than 5d. per Centner.

Peat prepared by the method above described is alleged to be superior to common or any kind of manufactured peat which has simply been air-dried, because its calorific power is much greater, on account of its containing considerably less hygroscopic water; and because, for the same reason, there is a saving in the cost of transport to the purchaser, who has less water to pay for under that head. The advantages with respect to its manufacture are stated to be:—easy and quick manipulation without any complicated machinery; moderate capital and comparatively small area required; and complete exemption from interruption in the manufacture on account of weather and time of year.

LINNING'S PROCESS.

A patent was granted to Linning in 1837 for the preparation of peat by pulping, compressing, and moulding; and the following extract from the specification contains a general account concerning this process:—"In the first place, reduce the mosses to a homogeneous pulpy mass, nearly in the same manner as brickmakers reduce their plastic material to a uniform state, namely, by passing through what they call a puggy mill, but which I fit with longer and sharper knives, somewhat obliqued. I then convey the moss so prepared to and place it on a table, platform, or floor, to be cut or moulded like bricks into any size or shape, either by the hand or by mechanical means. These blocks or pieces are then exposed or subjected to more or less pressure by means of levers, screws, hydraulic presses, or other compressing power or apparatus, and transferred to and arranged in a close chamber heated by flues or a stove, or to a kiln, in order that they may dry or consolidate from the evaporation of the moisture they contain. Exposure in this manner to an artificial heat produced by or obtained from the substance itself, and raised from 70° to 120° F." [21·1° to 48·9° C.] "or higher for a period of 24 hours, will probably be sufficient to dry the manufactured article completely, as will be easily discernible, and which is obtained in a very hard and

⁴ Improvements in the Preparation of Fuel from Peat-moss or Bog, Michael Linning, Feb. 6, 1837, No. 7926.

dense state, and may be used for the same purposes as pit-coal, with the advantage that it is free, at least generally so, from sulphur."

Only one patent relating to peat seems to have been previously granted in England, and that is dated April 15, 1620.⁵ I am not aware whether Linning carried his process into practical effect. The machinery which he adopted for pulping is essentially the same as that which has been described in the specification of numerous subsequent patents, and erected at several peat-works on the Continent; but whether in any case before the date of Linning's patent, I do not know. Thus in the treatment of peat by Weber, Gysser, Schlickeysen, Ekman, Versmann, Buckland, and Leavitt, pulping is effected in pug-mills approximating more or less closely in construction to the common machine, used by brickmakers for grinding clay, and adopted by Linning for grinding peat.⁶

BUCKLAND'S PEAT MACHINE.

At the International Exhibition in London in 1862, Buckland's machine was shown in operation. It consisted of an obtuse iron cone, having a spiral groove on its exterior, and revolving vertically and concentrically with the apex downwards, within a hollow cone of iron plate perforated everywhere with small holes just like a colander. The peat was put into the space between the solid and hollow cones, and by the rotation of the former was squeezed through the holes in the latter and extruded in the form of worm-like pieces. Thus prepared, it was ready for moulding, and a machine for effecting this was also exhibited in operation. The compressed peat-bricks were artificially dried, and samples of them were shown which were solid and resisting.⁷

SCHLICKEYSEN'S PEAT MACHINE.

It is stated that this machine has been used in Germany since 1860.⁸ The peat is pulped in a vertical cylinder, in the axis of which a shaft rotates carrying projecting blades, which are strong,

⁵ See Abridgments of Specifications relating to the Preparation and Combustion of Fuel, 1867.

⁶ Further information on this subject will be found in Johnson's volume on Peat and its Uses.

⁷ The preceding account is nearly the same as that which appeared in *The Times* newspaper, Sept. 9, 1862, and which I wrote. In the Official Catalogue the machine was described as Brunton's; but the attendant assured the jury, of which I was a member, that it was the invention of Mr. Buckland, formerly of the Maesteg Iron Works, South Wales. It was patented in the name of William Henry Buckland, Sept. 30, 1859, No. 2218. According to Johnson (*op. cit.* p. 151), Buckland's machine has been tried near Boston, U. S.,

and abandoned as uneconomical. Versmann invented a machine (see Johnson, *op. cit.* p. 150) which is reported to be identical in principle with Buckland's, but differing from it in having spiral knives instead of spiral grooves on the inner cone. Johnson states that it was patented in London in Sept. 1861; but I find no record of such a patent in the Abridgments of Specifications relating to the Preparation and Combustion of Fuel, 1867, or in the Indexes at the Patent Office.

⁸ It was patented in England, May 3, 1862, No. 1322. The information here presented concerning it, is chiefly from Johnson (*op. cit.* p. 144), who quotes from Dingler's *Polytechnisches Journal*, 1862, clxv. 184, and 1864, clxxii. 333.

and have cutting edges, and are so placed as to force down the peat. The blades are arranged nearly, but not exactly, in a true spiral, the effect of which is that they act unequally upon the mass, and mix and divide it more perfectly. There are no blades or projections fixed to the internal surface of the cylinder. The peat descends from a large hopper, through which is prolonged the rotating shaft fitted with a scraper, which prevents the peat from sticking to the sides, and forces it downwards. The pulp is driven out sideways through one or more nozzles inserted close to the bottom of the cylinder, and issues in the form of "a continuous block or pipe," that is cut off in suitable lengths either by hand or by mechanism. The addition of water is unnecessary in any case; indeed, the peat may with advantage be previously air-dried. Although wet peat may be worked with less expenditure of power, yet in that state the moulded blocks are so soft as to require much care in handling, and must be spread out in single courses, as they will not bear to be piled one upon another. In Livonia, near Pernau, two of Schlickeysen's machines (of the size No. 6) were put in operation upon a purely fibrous peat, and driven by an engine of 12 horse-power. The peat was ploughed up, once harrowed, and then carted direct to the hopper. These two machines, with 26 men and 4 horses, produced daily 60,000 peats, or 7500 cubic feet. It is reported that in heating effect 100 cubic feet of these peats were equal to 130 cubic feet of fir-wood, and cost only two-thirds as much. The peats were extremely hard, and dried in a few days sufficiently for use. In 1864, five large Schlickeysen machines were in operation at one establishment at St. Miskolz, in Hungary. The smaller-sized machines are easily portable, and adapted either for horse- or hand-power. According to Leo, one of the largest machines, provided with two nozzles, will, working at the rate of 112 revolutions per minute, produce 50 peats, and may be driven by an engine of 5 horse-power. This fuel is declared to be well adapted for locomotive and marine engines, to burn with a beautiful flame, and yield a firm and coherent coke.⁹

LEAVITT'S PEAT-CONDENSING AND MOULDING MILL.¹

In the United States, Mr. T. H. Leavitt, of Boston, has patented machinery, which is in operation at East Lexington, Mass., at the works of the Boston Peat Company. The process is essentially identical with that of Weber, but the hot-drying is omitted. The fresh peat is pulped or cut fine, moulded into blocks, and dried on light frames in the open air. According to the results claimed by Mr. Leavitt, his machine is very efficacious. It consists principally of a strong box or cistern, 3 feet in diameter and 6 feet high. The mill is adapted to be driven by a 4 horse-power engine. "The upper

⁹ Allgemeine Berg- und hüttenmännische Zeitung (Hartmann), 1862, iv. 53.

¹ The description in the text is taken from Johnson's volume on Peat and its Uses, p. 146. Since this was in type, I

have perused the somewhat more detailed description, given by T. H. Leavitt himself, in a volume entitled "Facts about Peat as an Article of Fuel," pp. 60 *et seq.* Boston, 1867.

portion of the box is divided by a series of horizontal partitions, the upper ones being open lattice-work, and the lower ones perforated with numerous holes. The upright shaft, which rotates in the centre of the box, carries a series of arms or blades, extending alternately on opposite sides; and as these revolve, they cut the peat, and force it through the openings in the diaphragms. The lower portion of the box, in place of complete partitions, has a series of corrugated shelves extending alternately from opposite sides, and the peat is pressed and scraped from these by a series of arms adapted to the work. By this series of operations the air-bubbles are expelled from the peat, and it is reduced to a homogeneous paste. When it arrives at the bottom of the box, it is still further compressed by the converging sides of the hopper, and it is received in light moulds, which are carried on an endless belt.* Powdered peat is used for preventing the prepared peat from adhering to the moulds. This mill, it is asserted, will condense 40 tons of crude peat daily, which, at Lexington, is estimated to yield 10 to 14 tons of dry merchantable fuel. The cost of producing the latter is asserted to be less than \$2 per ton; while its present value in Boston is \$10 per ton. It requires seven men, three boys, and two horses to dig, cart, mill, and spread the peat. The machine costs \$600; the needful buildings, engine, etc., from \$2000 to \$3000. The peat manufactured by this machine is stated to be of excellent quality. The drying in the open air is said to proceed with great rapidity, eight or ten days being ordinarily sufficient in the summer season. The dry peat at Lexington occupies one-fourth of the bulk, and has one-fourth to one-third of the weight of the raw material, which, it is asserted, is by no means saturated with water, but well drained and considerably dry before milling.

PROPOSAL TO GET AND PREPARE PEAT BY FLOATING MACHINERY.

A few years ago, subsequent to 1866, I had an interview in London with Mr. Hodges, of Canada, on the subject of a process for getting and preparing peat, which he had patented and described in a pamphlet illustrated with picturesque engravings on wood, after having devoted three years to preliminary experiments on a considerable scale.² Although he had not up to that time attempted to put his scheme into practice, nor, as far as I am aware, has since done so, yet a short account of it may be acceptable to persons who are interested in the application of peat to metallurgical operations. Accordingly, the following extracts from the pamphlet above mentioned are here inserted:—

“An extensive undrained bog, from 8 to 12 feet in depth—or, if deeper, the better—having been selected, the first process is to trace out at some distance from the margin a contour level line of, say, several

* Date of the patent, June 17, 1864, No. 1511. See Abridgments of Specifications relating to the Preparation and Combustion of Fuel, 1867, p. 1157.

miles in extent. Along this line a space of some 19 feet in width must be cleared, and the live moss or turf entirely removed; by the side of this a space 90 feet in width is to be cleared and drained to receive the pulped peat. At one end of the contour line before mentioned, a barge or scow, 80 feet long, 16 feet beam, and 6 feet deep, must be constructed and launched into a hole dug in the bog to receive her. The barge or scow is to contain all the machinery necessary for the complete manufacture of the peat. At one end of the scow is placed a pair of large screw-augers 11 feet in diameter, which, being provided with proper shafting and gearing, are made to revolve by means of a steam-engine placed on the rear of the vessel. These augers or screw excavators bore out the peat in precisely the same manner that a common auger bores itself into wood; and the scow being made to move onwards as the boring proceeds, it follows that a canal 19 feet wide, and from 4 to 6 feet deep, is formed, in which the scow with her burden of machinery floats, the water from the adjacent peat draining into and filling the canal as fast as it is made, the usual speed of the scow being some 15 feet per hour. A competent engineer should determine and lay out the canal level, as well as arrange its water supply, upon which depends in a great measure the successful working of the whole. The peat, when bored out or excavated by the screws, is delivered into the barge and conveyed by means of an elevator to a hopper, into which it is tumbled. It then passes through machinery which removes all sticks, roots, and, eventually destroying the fibre, reduces the peat to a homogeneous mass of soft pulp, like well-tempered mortar. This pulp then passes into a long spout or distributor, which, extending at right angles over the side of the scow, spreads out the pulp upon the levelled moss by the side of the canal in a thin slab 9 inches in thickness and 90 feet in width. After the slab of pulp has been deposited for a couple of days, or in hot weather for a shorter period, it begins to consolidate and show symptoms of cracking. Immediately any cracks make their appearance, it must be marked out by drawing a framework, carrying curved knives placed 6 inches apart across it. A few days more hardens the pulp, so that by the aid of boards a man can walk on it, and mark it longitudinally with cuts 18 inches apart. In about a fortnight the shrinkage of the pulp slab causes the cuts made in it to open, and the whole presents the appearance of an immense floor covered with bricks 18 inches long, by 6 inches wide. As soon as the bricks are sufficiently hard to bear handling, they are separated and 'footed,' that is, set up on end, five in a stook, with one across the top, in which position they remain until dry enough to be removed to the store or to market.

"In forming or uncovering the canal track, nothing more is required than that the turf or live moss, about 6 inches in thickness, together with the roots of all trees upon the surface of the bog, should be removed; and as upon all undrained bogs the roots of such stunted trees as grow there are all on the surface [? J. P.], this operation is easily accomplished.

"In the preparation of the pulp beds great care is required, and a surface should be obtained as level and even as possible. The roots of all trees must be removed, and this is more readily accomplished with the trees themselves, by which means considerable labour may be saved, one man pulling them down on one side, while another with an axe cuts the lateral roots at some distance from the stem, leaving the smaller portions behind. The long grass, shrubs, and rank mosses are cut down with a short scythe, and used in filling up any irregularities on the surface. Drains from 9 to 12 inches deep should also be cut, and covered over with the spare turf taken from the canal track. The soil from the drains may also be used in levelling and filling up inequalities in the pulp bed. In some places where the growth of shrubs has been very rank and coarse, the turf upon the whole surface of the pulp beds has been cut into strips and inverted; but it is better to cut drains and leave the turf in its natural position. The soft pulp, when poured upon it in a semi-fluid state, advances, lava-like, pressing down any small branches of shrubs and the long grasses which may be standing in the way of its onward progress. The pulp should not be deposited nearer than 5 feet of the canal, and upon this space may be placed any surplus moss or turf from the uncovering of the canal track, which will not only keep the pulp in place, but also form a road and towing-path for the canal. At the rear, or 90 feet from this bank, a double thickness of turf is all that is necessary to complete the pulp beds.

"The canal track and pulp beds being prepared, and the scow with its machinery in position, nothing more is required than to set it in motion, giving the necessary feed—say $1\frac{1}{2}$ inch for each revolution of the screw excavators—which may be increased to 3 inches, or more if necessary. As the screws revolve, they cut off continuous slices of the peat, which, by the assistance of a couple of men, are delivered through the rear of the shield the screws work in, into a well in the bow of the scow. These men also remove any large masses of extraneous material, such as pieces of wood, roots of trees, etc., which may work in. It is sometimes required, when working in peat which is very full of roots, to have a man placed in front to remove them as they are brought up by the knives of the screws, roots as much as a man can lift being occasionally excavated. After the peat is delivered into the well, it is carried by means of an elevator and tumbled into a hopper, from which it passes through the stick and fibre catcher to the pulping and distributing trough without any assistance whatever, it being only necessary to see that the stick catcher is kept clear; and occasionally, when the pulp is too stiff or dry, to turn on a pump until it is reduced to a proper consistency.

"The levelling of the pulp should be done as evenly and as smoothly as possible. A few days' experience will enable any intelligent man to accomplish this, and upon its being well done depends in some measure the quality of skin upon the peat, so essential not only in shedding the rain and preventing cracking from the sun, but also for giving a permanent toughness to the bricks.

"The crew of the scow, all told, will number six, including the master, who keeps the knives of the screw-excavator clean, and sees that all is going on right. Two men act at the screw-excavators, one engineman, one man levelling the pulp, and one man to attend to the stick-catcher and pulping-spout.

"The marking of the pulp beds into transverse cuts, at 6-inch intervals, is proceeded with as soon as the pulp begins to set, or becomes so tough that, when the incisions or cuts are made in it by the knives, they do not re-unite. The operation is performed by two men, one on each side of the pulp bed, who by means of a rope pull a framework of wood, carrying curved knives, to and fro across the bed. A little practice enables them to perform the work with great accuracy. The longitudinal cuts, 18 inches apart, are made as soon as the pulp is sufficiently hard to bear the weight of a man upon a plank laid on its surface. It is performed by pushing a circular plate of iron, which, cutting like a circular saw, severs the peat to the very bottom. In making these last cuts care should be taken that they go quite through the peat, so that surface water from rain may freely pass off through the drains in the pulp beds into the canal.

"Upon the state of the weather depends the time when the next operation should be performed; but if the pulp slab, when first spread out, is not more than 9 inches in thickness, which it should never exceed, then a fortnight will be ample time to harden the bricks for footing. The footing is done by gangs of men and boys—one man and three boys working together; the man, using a suitable tool, separates the bricks, which the boys foot, or place in groups or stooks of five; four stand on their ends, inclining to each other, with their tops touching, the fifth being balanced horizontally upon them. A man and three boys will foot 4000 bricks in a day. After the bricks have been exposed to the weather for a few days, they should be re-footed or turned, two boys handling 4000 as a day's work. Nothing now remains to be done but to wheel the bricks, when sufficiently dry, into barges, and convey them to the store.

"In all cases peat fuel is more solid, and stands the blast [in the fire-box of a locomotive] better, if removed from the ground and dried in large heaps, at a time when it contains some 30 per cent. of moisture. If it is allowed to become too dry by the action of the sun, it cracks, and the loss therefrom is considerable.

"In a climate like that of North America, where the working season is limited, no time should be lost, but as soon as the frost is out of the ground, the machine should be at work, and continue without interruption day and night until within some three or four weeks of the time the frost may be expected. The effect of frost upon peat not harvested is to destroy the cohesion of its particles, and this in either a raw or manufactured state. For instance, peat-bricks partially dry and then frozen always remain of the same bulk as when attacked by the frost; no amount of drying will make them shrink or become hard; they absorb moisture very readily, and part with it very tardily. Indeed, when peat fuel has been frozen, it is next to impossible to get

it dry except by housing it carefully; and if it happen to be very wet when frozen, it is of little more value as fuel than unmanufactured peat. Frozen peat, dried, pulverised, and compressed, makes very good fuel for domestic use, but it will not stand the blast, and is therefore unfit for raising steam or for manufacturing purposes. In its natural state peat is effectually protected from frost by its covering of live moss and water; but as soon as this covering is removed, frost penetrates to a considerable depth, entirely destroying its cohesive properties, which cannot be restored by any amount of pulping. It is therefore certain that by draining a bog, and removing its natural covering, its value is much deteriorated for making a first-class fuel. Peat exposed to the sun and partially dried is affected in the same way as by frost, and will not become hard when pulped.

"Early in the month of October 1865, the writer, for the sake of experiment, dug a canal nearly a mile in length, 19 feet wide, 5 feet deep, pulped the peat excavated, and deposited it alongside of the canal, where it formed an embankment 36 feet wide and 2 feet 6 inches deep. This bank subsided considerably, until the frost set in and penetrated during the winter to a depth of 15 inches. Below this depth the pulped material was uninjured, and in the following summer, when dug out and cut into the shape of bricks, it dried, became hard and solid, making excellent fuel, while the whole of the upper or frozen portion was little better than unpulped peat. The embankment was firm and elastic to tread upon, and all that could be desired as a formation for railway purposes; but it never became hard, neither was it during the hot days of July dry to a greater depth than half an inch. This embankment remains as perfect as when first formed, and to an engineer is well worth a visit of inspection.

"It is not absolutely necessary that the fuel, when well harvested, should be put under cover. It may be stacked, as it is in Ireland, in large heaps, the weather having but little effect on it; but, like wood, coal, or coke, exposure to the atmosphere for any length of time is injurious, and the cost of placing it under cover is more than repaid by the improved quality of the fuel."

COMPRESSION OF PEAT INTO BALLS AND OTHER FORMS.

When unbroken flat bricks of compressed peat are thrown into a fireplace, they may fall over one another on their large surfaces, so as to impede more or less the passage of air through the mass. With a view to prevent this inconvenience, compressed peat has been manufactured in Southern Bavaria in the form of round balls.* Fuel in the form of balls was proposed in the sixteenth century by Hugh Platte, and an engraving of a fire-place filled with such fuel, ignited, is

* Wagner's Jahresbericht, 1861, vii. 703.

given in his well-known work.⁴ These balls seem to have consisted of a mixture of fine coal and clay, and resembled those which to this day continue to be made in some parts of Ireland. Platte expressed his readiness to disclose his invention "upon reasonable considerations, to such as should be willing to entertain them or to procure some Privilege for them."

Compressed peat in the form of cylindrical cakes, and pipes of the same material half an inch in bore, 2 or 3 inches in diameter, and about 1 foot long, have also been manufactured.⁵

INTERMIXTURE OF PEAT AND OTHER SUBSTANCES.

Should any person of ordinary intelligence be disposed to wade through the dreary specifications of patents relating to the preparation of peat for fuel, he will perceive that frequently the same thing has been patented several times, and that in not a few cases the patentees have displayed astounding ignorance of the subject.⁶ A portion of the large sum annually abstracted from the pockets of inventors would be most equitably and usefully expended upon a special and intelligent tribunal for the administration of patent law, having for one of its chief objects the consideration of the soundness of the claims on legal or other grounds of applicants for letters-patent. If such a tribunal existed, many an unhappy patentee would be prevented from exhibiting his folly, and wasting the money which he can ill afford to lose. The expenses of such a tribunal could be defrayed, without having recourse to the imperial revenue, out of the large *surplus* income, exceeding £50,000, arising from the duties and fees paid by patentees.

The Balance Sheet of Income and Expenditure annexed to the Report of the Commissioners of Patents for 1872 is instructive, and some of the items of expenditure are worthy of note. The first two are:—

| | £ | s. | d. |
|---|------|----|----|
| "Fees to the Attorney-General of England..... | 5538 | 15 | 0 |
| "His clerk..... | 491 | 10 | 0" |

These sums were paid, *nominally*, on account of the duties which the Attorney-General's clerk is expected to discharge, in seeing that the papers of each applicant for letters-patent are in *due legal form*, and

⁴ The Jewell House of Art and Nature. Containing divers rare and profitable Inventions, together with sundry new experimentes in the Art of Husbandry, Distillation, and Moulding. Faithfully and familiarly set downe, according to the Authors owne experience, by Hugh Platte, of Lincolnes Inne Gentleman. London, Printed by Peter Short, dwelling on Breadstreet hill, at the signe of the Star, and are to be solde in Pauls Churchyard.

1594. See also the specification of a patent granted to Messrs. Gwynne, and dated Dec. 3, 1853, No. 2817.

⁵ Johnson, Peat and its Uses, pp. 102, 140, and 144.

⁶ See the following specifications:—G. Lowe, Oct. 8, 1846, No. 11,405; G. H. Bovill, Aug. 6, 1858, No. 1791; C. Kingsford, July 15, 1859, No. 1671; W. Bennett, Aug. 19, 1861, No. 2053; G. Evans, Nov. 2, 1861, No. 2761.

to remunerate the Attorney-General himself, for attaching his signature to certificates of that fact. The questions of real importance, in regard to each application, have been left by the wisdom of the Legislature to the judgment and conscience of the applicant, who is required to declare, that the invention, he "*believes*, will be of great public utility," and that he is "the true and first inventor thereof."

Formerly, sums of nearly the same amount appeared in the Balance Sheet as fees to the Solicitor-General and his clerk, the work in question being distributed between the two law officers of the Crown and their respective clerks. But under a recent Act of Parliament⁷ and a Treasury minute, the fees of both the law officers have been commuted, and they are to receive instead, the Attorney-General £7000, and the Solicitor-General £6000 per annum. The Attorney-General at the time the Act was passed, now Lord Coleridge, was however exempted from its operation; hence the statement of fees paid to him in the Balance Sheet for 1872.

Though, *nominally*, for services in connection with the granting of patents, yet, in reality, these fees and salaries appear to be paid for very different reasons. For, when the Scotch and Irish patent offices were abolished in 1852, the fees of the Scotch and Irish law officers and their clerks (whose duties then came to an end) were commuted for salaries amounting in the aggregate to £3450. These salaries, however, were not merely paid to the then holders of the offices in question, but have been paid to all subsequent holders, and *the above sum of £3450 still appears in the Balance Sheet under the head of "Compensations."*⁸

No reasonable man would grudge these gentlemen salaries commensurate with their varied and arduous duties; but the inventor may justly complain of the appropriation of his money for such purposes, so long as the demand for a proper tribunal to administer patent law is disregarded.

Of the various substances which have been patented for admixture with peat, with a view to improve its quality as fuel, may be mentioned resin, pitch, tar, oil or "other hydrocarbonaceous matter," turpentine, and petroleum. There can be no doubt that the calorific value of peat would be increased by the intermixture of those substances, but, it must be asked, at what cost? That is the question. So far as the author is aware, not a single intermixture of the kind has been found economically advantageous on a large scale, and certainly not one has come into general use. Mixtures of peat and variable proportions of "vegetable or mineral carbon," with or without slaked lime, have been patented.⁹ Claims for the use of the following substances in admixture with peat will be found in various

⁷ The Law Officers' Fees Act, 1872, 35 & 36 Vict. cap. lxx.

⁸ See the 50th section of the Patent Law Amendment Act, 1852, 15 & 16 Vict. cap. lxxxiii. It would seem at least

doubtful whether Parliament contemplated these permanent "*Compensations*."

⁹ See the specifications of G. Evans, dated Nov. 2, 1861, No. 2761; and W. B. Stones, March 7, 1850, No. 12,990.

specifications relating to peat:¹—Caustic, as well as carbonate of, soda or potash, sulphate of potash and alumina, nitric acid, hydrochloric acid, hypochlorite of lime, nitrate of potash, of soda, or of lime;² potash, lime, magnesia, manganese, soda, phosphoric acid, alkalies, fluorine, fluoride of calcium, silix, or any combinations of lime, with a view to their action in metallurgical operations;³ nitrate of lead,⁴ ammoniacal water, ferrocyanide of ammonia (*sic*) and potassium, “a metallic chloride or an acetate of iron,” or “a bath of dilute ammonia and a bath of acetate of alumina may be substituted,” fermenting agents, such as yeast, albumen, etc.;⁵ quicklime, bisulphate of soda, alum, sulphate of strontian.⁶ It would be impossible to imagine anything more absurd for admixture with peat than some of the substances here specified.

DESICCATION OF PEAT.

The desiccation of peat is a subject which demands special and separate consideration, with respect to the use of that fuel in metallurgical operations requiring high temperatures. Air-dried peat contains, as we have seen, not less than one-fourth of its weight of hygroscopic water, which during combustion must be evaporated at the expense of the heat developed by the oxidation of the organic constituents of the peat, thereby causing great reduction in temperature. Hence it will be obvious why attempts should have been made to prepare peat as free as possible from hygroscopic water. The methods which have been proposed for that purpose are of two kinds: one in which artificial heat alone is resorted to, and the other in which that agency is supplemented by mechanical compression; but, in every case, except, probably, in that of powerful compression, the peat should first be air-dried, in order that it may slowly part with the great bulk of its water and shrink uniformly without cracking. Moreover, it has been previously stated that, when wet peat is exposed to artificial heat, it dries externally into a hard crust, which impedes desiccation and causes fissuring of the mass. It is possible to expel all the hygroscopic water from peat by artificial heat; but the dry product would in the course of a short time absorb from the atmosphere as much water as the same peat contains in its air-dried state. From the last statement it follows that no advantage would be gained by lessening the quantity of water in air-dried peat, if it is afterwards left exposed to the atmosphere, though, by stacking it closely in mass, a considerable time might elapse before it would absorb as much water as air-dried peat contains.

¹ See Abridgments of Specifications relating to the Preparation and Combustion of Fuel, 1867.

² J. M. H. Perodeand, Nov. 26, 1853, No. 2765.

³ Messrs. Gwynne, Dec. 3, 1853, No. 2817. The substances are for the most

part presented in the order in which they are mentioned in the specifications.

⁴ E. Maniere, June 5, 1854, No. 1248.

⁵ M. de la Fenestre, July 14, 1859, No. 1667. Provisional protection only.

⁶ W. Clarke, Sept. 26, 1861, No. 2412.

Various methods have been proposed for drying peat by artificial heat, the principles of which consist in the application either of hot air, of radiant heat, or of a combination of both. In Weber's drying chambers, previously described (see p. 242), the first of those principles seems to be applied in a satisfactory manner; and only waste material is used for heating the air, such as the stumps and roots of the trees which occur in the turbary at Staltach, and must be gotten along with the peat.

The drying of peat has also been effected in closed kilns through which the gaseous products of the combustion of peat or other fuel have been made to pass, either from below upwards, or from above downwards; and with those products atmospheric nitrogen, and more or less free oxygen, would always be associated in considerable quantity.

It is reported that at Lippitzbach, in Carinthia, and at Neustadt, in Hanover, a kiln of the following construction has been used.⁷ It consists of a chamber rectangular in plan, of which the walls are vertical, and the roof is arched. Within about one-fourth of its height from the bottom, it is divided horizontally into two compartments (A and B) by an arched floor, in which are numerous and symmetrically arranged openings, the upper and larger compartment (A) intended to receive the peat, and the lower and smaller one (B) to supply heated air. The compartment B communicates directly with an adjacent fireplace on the outside of the chamber. In the wall forming the side or back of the chamber opposite the fireplace is a vertical chimney with a damper at the top, which in height a little exceeds that of the kiln, and communicates with A, immediately above the perforated arched floor. In the middle of the roof is an opening for charging, fitted with a movable cover; and it is to be presumed that there is also a suitable doorway below for withdrawing the dried peat, though no indication of one is shown in the engravings which I have seen of this kiln. The perforated arched floor is on a level with the ground, and the kiln is built of brick or stone. In charging, the peat must be so stacked in the compartment A as to permit the circulation of the ascending hot gases through the mass. Peat is the fuel used for heating, and the fire requires to be carefully regulated by means of the damper. It is supposed that when the kiln is in full operation, the gaseous products of combustion rise through the peat to the roof, and having in their course thither been deprived of the greater part of their heat and become loaded with moisture and heavy in consequence, thence descend along the walls to the bottom of the compartment A, and escape through the chimney into the open air. The gaseous products on entering the chimney are, it is conceived, only in part and not wholly cooled down; for in that case the chimney would cease to draw and the heating stop, with consequent risk of the condensation of water in

⁷ See the German translation by Knapp | i. 397; and Johnson's volume on Peat
of the first edition of this work, i. 92; | and its Uses, p. 154.
the French translation of the same work,

the peat near the back wall and on that wall itself, especially since very watery fuel is used for heating the chamber. Although [theoretically] the gaseous current should proceed in the manner indicated, yet in actual practice it is difficult for it to take that course. In fact, the gaseous current, when it has once reached the roof, will and must descend not only along the back wall, but also along the three other walls; it finds, however, no direct outlet at the foot of those walls, because it is there met by the ascending gaseous current. Finally, the ascending gaseous current from the lower compartment *a*, near the back wall, would hardly prefer the contracted and difficult course through the stacked-up peat to the nearer and direct passage into the chimney. Both deviations lessen the efficiency of the drying-kiln. The foregoing account is a nearly literal translation of that by Knapp, which is accompanied by an engraving of a vertical section of the kiln, showing the supposed direction of the gaseous current by means of numerous arrows. The theoretical part appears to be somewhat fanciful; for it is not easy to understand why the gaseous current should take the roundabout course of ascending to the roof of the kiln and then descending to the outlet at the bottom of the chimney.

The principle of drying peat in a chamber or kiln, by burning fuel in a fireplace forming part of the kiln itself, has been applied in various ways; and much ingenuity has been shown, especially in Germany, in the construction of such kilns. The hot gaseous products of combustion have not in some kilns been conducted into the interior and then through the mass of peat, but have been made to perform the work of desiccation indirectly through the medium of radiant surfaces. Weberling used radiant heat in kilns, which he erected at ironworks near Aalen, in Würtemberg, for the desiccation of wood as well as peat, and which are said to be amongst the oldest and best known.^a A kiln of this kind is a rectangular chamber, formed of four vertical brick walls, a flat bottom of iron plate, which may be termed the floor-plate, and an arched roof. In the lower part of the front wall is a door, used both for charging the wet and drawing the dried peat. At a short distance in front of the back wall the kiln is divided by a vertical partition wall, which above a certain height from the floor-plate has numerous holes in it, just like the loose brickwork on the top of a prison wall. Under the door is a fireplace, from which the smoke passes through a tortuous system of flues, which are covered in above by the floor-plate; and when it reaches the flue under the bottom of the space between the partition and back walls, it rises through one leg of a syphon-like wide pipe of cast-iron, contained within that space, and descends through the other leg, which communicates with the chimney at the back. The peat is piled on a wooden stage of trellis-work, fixed at a short distance above the floor-plate. The peat

^a Der Torf, seine Natur und Bedeutung, by A. Vogel, p. 56. The following account is taken from this volume, in which it is illustrated by a vertical cross-section

and a plan of the kiln, which do not agree with each other, and are not drawn to scale.

remains in the kiln during several days, and it is used for puddling-furnaces as soon as it is withdrawn. The performance of the kiln is reported never to have been very satisfactory, vapour escaping but slowly through the holes in the partition wall, and the fuel consumed in the process amounting to as much as $\frac{1}{3}$ or $\frac{1}{4}$ of the peat dried.

Kilns have been constructed in which the hot waste-gas of furnaces has been driven in through the roof by means of a fan, made to descend through the peat, and thence to pass into a chimney communicating with the interior of the kiln at the bottom by two flues, one on each side. Kilns on this principle are said to have been first introduced by Schlägel into Austrian smelting-works, and extensively adopted, especially in French smelting-works.⁹ At some Austrian smelting-works, according to Vogel, the charge of peat was stacked in an iron waggon, running on rails into the kiln, dried thereon, and withdrawn in the same waggon. The kilns were heated by the hot waste-gas (*Feuerluft*) of furnaces, which was sucked by a fan through pipes communicating with the chimneys, and injected just below the highest part of the arched roof, an outlet being provided near the floor on each side. Occasionally cold atmospheric air was supplied to the suction-pipes along with the gas, in order properly to regulate the temperature and prevent ignition of the dry peat, of which, it is said, there was not a little risk; and on account of this risk the kilns were made proportionately small. The temperature at which desiccation was effected was sometimes higher and never lower than 100° C. The drying process was usually completed in from 2 to 3 days, and the cost was very considerable, often amounting to 1 Florin 36 Kreuzer (about 2s. 5d.), and more, per 1000 pieces of peat (the size of which is not stated), which is nearly as much as the total cost of the peat (exclusive of that of drying); and it can only be applicable where heating material, involving no additional charge, is available, or where complete desiccation (*vollständige Röstung*) of the peat is regarded as essential.

In other kilns, heated air has been driven in near the bottom. Tunner, writing in 1858, states that such kilns were in use at Freudenberg, in Carinthia.¹ They were square in plan, 20 (Vienna) feet on the side (1 Vienna foot = 1.037 English foot), having vertical walls 9 feet high (inside measure), and an arched roof. At the height of 3 feet from the floor was a stage of wooden trellis-work, on which the peat was piled. In the middle and lower part of the front wall was a door for drawing out the peat, and there were as many as six square holes in the roof for charging. At the distance of about 1 foot under the trellis-stage were two flues 4 feet wide, extending from front to back, parallel to the

⁹ Knapp's translation of the first edition of this work, i. 93. See also Zerner's work on gas-furnaces, entitled, "Einführung, Fortschritt und Jetztstand der metallurgischen Gasfeuerung im Kaiserthume Oesterreich," 1856, pp. 175-199. This volume contains much

valuable practical information concerning the use of peat as fuel in the manufacture of iron.

¹ Die Stabeisen- und Stahlbereitung in Frischherden oder der wohlunterrichtete Hammermeister, 2nd edition, 1858, i. 26.

sides of the kiln; and in each of the sides of the flues, beyond the distance of 7 feet from the front, was a series of ten holes, or a total of forty in the two flues. The distance between the side of the kiln and the side of the flue adjacent was 3 feet. Heated air was forced into the flues, whence it escaped through the forty holes in their sides, and rose through the trellis-stage and overlying peat. Into such a kiln, which was capable of holding more than 3500 cubic feet of peat, air, heated to from 130° to 150° C., was injected at the rate of about 350 to 400 cubic feet per minute. At first the vapour was allowed to escape through the charging-holes in the roof, but afterwards these were stopped up tight, when the vapour passed out a little above the trellis-stage through the discharging-door. The current of heated air was kept up uninterruptedly during 4 or 5 days, and 3 or 4 days were required for cooling, emptying, and charging again. The peat did not seem to be very uniformly dried, and ignition not unfrequently occurred within the kilns.

Ekman's PEAT-KILN.

In 1856 the distinguished Swedish ironmaster, Gustaf Ekman, after several unsuccessful attempts to construct satisfactory kilns for the drying of peat, erected one on Schlägel's principle at the Lesjöfors Works, with, it is reported, an entirely favourable result; but the gaseous current, instead of being forced in, was produced by the exhaustion caused by a fan communicating with the bottom of the kiln.² A representation of this kiln is given in the woodcuts on the next page, figs. 34-37.

The kiln is heated by the waste-gas of a charcoal finery, *a*, which gas after having been used for heating pig-iron, the blast of the finery, and an annealing-furnace, passes into the so-called spark-chamber (*Funkenkammer*), *b*, and is there cooled by cold air admitted through the opening, *c*, in the roof of the chamber. By more or less closing this opening, as well as the top of the finery chimney, by means of a damper, the temperature of the kiln is regulated. From the spark-chamber the gas goes into the vertical shaft, *d*, thence through the opening, *e*, into the kiln, *m*, and then descends through the peat into the horizontal flue, *f*, towards the exhausting fan, *n*. The whole space above the trellis-work, *h*, up to the level of the charging-door, *g*, is filled with pieces of peat. The dried peat is withdrawn through the two doors, *i i*. When the supports, *k k*, are loosened, the boards, *l l*, suspended on hinges upon the other side, drop down, and the peat then falls into baskets underneath. In order that the withdrawal of the peat may take place as uniformly as possible across the kiln, there are four rows of such boards, *l l l l*, each containing four separate and

² A description of this kiln, with illustrative drawings to scale, was published by Dellvik in 1858 in the *Jern-Kontoret's Annaler*; and a translation of it in Ger-

man by Tunner appeared in the *Berg- und hüttenmännisches Jahrbuch*, 1860, ix. 95-117, under the title "*Ueber Torfbereitung und Anwendung in Schweden.*"

similar boards, so that the peat may be withdrawn at sixteen different places at the same level. In charging, care must be taken to spread the "peats" evenly over the whole cross-section of the oven. The peat is withdrawn and stacked according to requirements and the drying capability of the kiln. There is but little interruption in the working of this kiln, as fresh peat is supplied at the top as fast as dry peat is removed at the bottom. The external diameter of the exhausting-fan is 5 feet 4 inches (nearly the same as English feet and inches), the

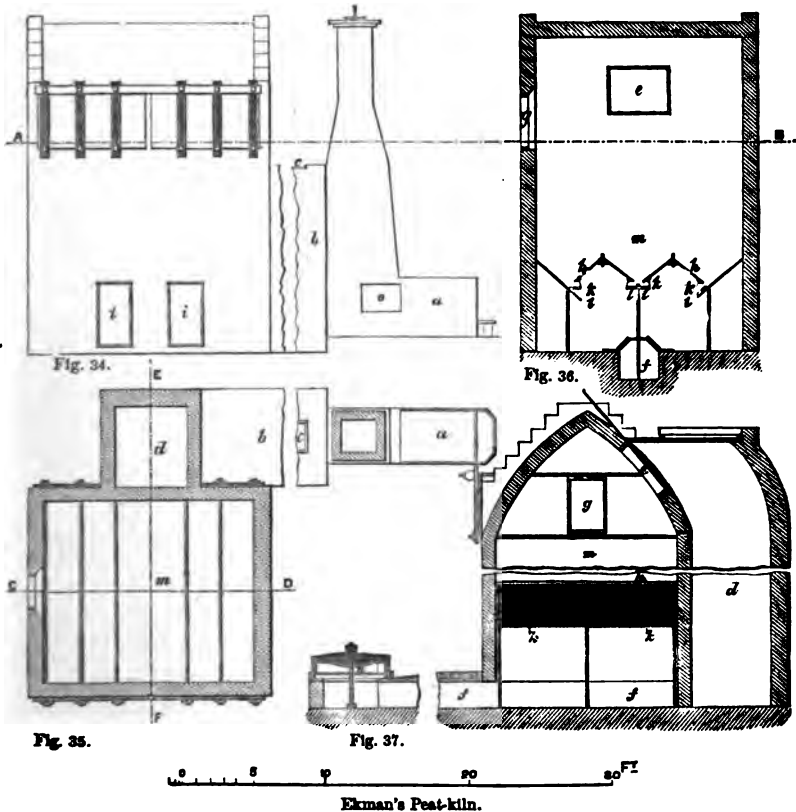


Fig. 34. Side elevation.

Fig. 35. Horizontal section on the line A B.

Fig. 36. Vertical section on the line C D.

Fig. 37. Vertical section on the line E F.

width of its vanes 1 foot, and their radial length 8 inches, and the outlet is 4 feet in diameter.

One advantage of this kiln consists in bringing the gas while hottest into contact with the peat while in its moistest state, so that the temperature of the former may be kept much higher without risk of causing the peat to ignite than in those kilns in which the gas while hottest comes first into contact with the driest peat. As, however, the peat in the lower part of the kiln is traversed by gas which has become loaded with moisture and reduced in temperature by

descending through the moist peat above, it might be supposed that it would be insufficiently desiccated; but in practice that has not been found to be the case; for it has been ascertained that the gas, after passing through the whole mass of peat, is far from being saturated with moisture. Moreover, in ordinary kilns, in which there is an upward draught, the gas will obviously tend to rise through the hottest parts of the kiln, or those in which the peat has become most desiccated, and, there, being less cooled and specifically lighter, it will ascend more rapidly where it is least required. Consequently, in those parts of the kiln where the peat is moistest, the gas will remain longer in contact with the peat, become more charged with aqueous vapour, and be thereby rendered specifically heavier to such an extent as to tend to sink and counteract the operation of the kiln. On the other hand, when the gas is forced downwards from the top of the kiln, it is said to be not only more equally diffused through the stack of peat, but to descend more rapidly in those parts where the peat is moistest, by taking up more aqueous vapour and becoming therefore specifically heavier, thus promoting the downward flow of gas where it is most needed; and the result is alleged to be that ultimately all the peat at the same level is dried to the same degree.

The temperature in the upper part of the kiln above described usually ranges from 100° C. to 110° C., but it has occasionally amounted to 140° C. and 150° C., being increased in proportion to the moisture in the peat or the frequency of the withdrawal of the dry peat. The chief point in the management of the kiln is to maintain, as far as practicable, a suitable temperature throughout the interior of the kiln. It is, however, obvious that the temperature cannot be uniform, owing to the difference in the rate of evaporation which must occur in different parts of the kiln. The walls and doors of the kiln should be made impervious to air; for, if currents of cold air entered from without, local condensation of moisture and inequality of desiccation might follow. When the fan makes from 130 to 190 revolutions per minute, the temperature in the upper part of the kiln ranges from 90° C. to 145° C., and below the trellis-work from 60° to 80° C. The most suitable velocity has been found to be from 180 to 190 revolutions per minute, by which about 6000 cubic feet of air per minute are exhausted. When the velocity was increased beyond that amount, there was too great a draught of cold air through the working-hole of the charcoal finery, and too great a reduction in the temperature of the gas passing into the kiln. A certain degree of cooling and mischievous draught cannot be avoided during the charging and drawing of the kiln, so that every arrangement should be made to perform that work as easily and quickly as possible. The drying space in a kiln of the dimensions shown in the woodcuts amounts to 2240 cubic feet; and it may be estimated that with ordinary management the peat will remain about 3 days in the kiln, and that the daily yield will be 5500 pieces of dried peat. After kiln-drying, the peats are 8 inches long, 3½ inches wide, and 2½ inches thick; the air-dried peats are 9 inches long, 4 inches wide, and 3 inches thick; 100 peats weigh on the average

83 lbs. avoirdupois; and the cost of kiln-drying is half a Florin (österreich. Währung, i.e. Austrian currency), or about 1 shilling per 1000 peats, or about 2s. 8d. per statute ton. The cost of getting, pulping, moulding, air-drying, and storing the air-dried peat at the Lesjöfors Ironworks, exclusive of interest and any deduction on account of repayment of capital, is reported to be 1 Florin 12 Kreuzer (ö. W.), or about 2s. 3d., so that the total cost of the kiln-dried peat is about 5 shillings per statute ton.

PEAT-KILN USED AT BERGEN, BAVARIA.

Hot-blast, that is, air mechanically forced through apparatus suitable for heating it to a considerable degree in its course, has been applied to the desiccation of air-dried peat at the Royal Maximilian Ironworks at Bergen, in Bavaria.³ The kiln employed for that purpose is a brick chamber, rectangular in plan, with vertical walls and an arched roof, in the middle of which is a hole provided with a movable cover. In the front wall, commencing at about 3 feet above the ground, is a rectangular opening fitted with an iron door, which is kept closed and luted during the process of desiccation. At about 1 foot from the floor there is a false bottom extending from the front wall to within about 9 inches of the back wall, and on this end of the false bottom rises a vertical cross wall to within a short distance of the roof. The false bottom consists of cast-iron girders, overlaid with a brick floor. The height from the lower surface of the false bottom to the highest part of the roof is 12 feet, the width of the front wall 10 feet, *outside* measure, and the length from the front wall to the partition wall at the back 10 feet, *inside* measure (1 Bavarian foot = 0.957 English foot). On the outside, and near each of the lower angles of the door, is a small square hole. Hot-blast, at about 150° C., is admitted under the middle of the front door into the space between the false bottom and the floor. The kiln is filled with 15 sacks (1 sack = 33 cubic feet, Bavarian) of air-dried peat, containing from 25 to 30 per cent. of water, thrown in at random, through the hole in the roof, and left as it falls; and the kiln-dried peat is drawn out through the doorway in front. The charging hole in the roof being closed, hot-blast is now let on, which travels backwards under the false bottom, rises through the space between the back wall and the inner partition wall in front of it, thence descends forwards through the mass of peat, and finally escapes, loaded with more or less aqueous vapour, through the small holes near the bottom of the front door, which at first are kept stopped, but are afterwards gradually opened as the air escaping from them becomes hot. Desiccation is known to be concluded when the blast comes out dry, and as soon as that occurs, the drawing out of the peat begins. The

³ The following account is derived from Ruttner's paper, previously quoted, in the *Berg- und hüttenmännisches Jahrbuch* for 1862, xi. 19 *et seq.*

kiln-dried peat still contains 10 per cent. of water, and is used immediately after leaving the kiln, in order that it may not absorb moisture from the atmosphere. It is consumed exclusively in the reheating-furnaces of the above-mentioned ironworks.

WELKNER'S PEAT-KILN.

An apparatus for the application of hot-blast to the drying of peat, and capable of being also adapted to the drying of wood and lignite or brown-coal, has been contrived by Carl Welkner, director of smelting works, near Lingen, in Hanover.⁴ It is represented in vertical section in the annexed woodcut, fig. 38.

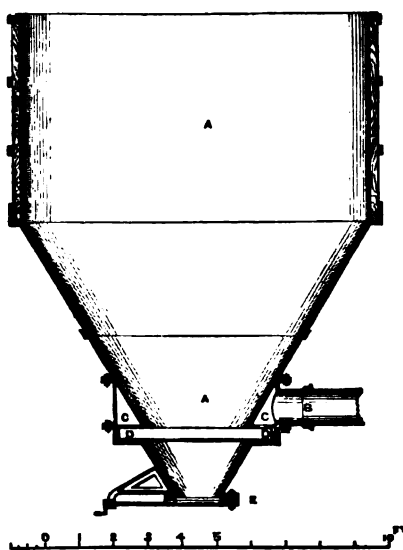


Fig. 38. Welkner's Peat-kiln. Vertical section through the centre.

A is the drying-chamber, open at the top, and fitted with a slide at the bottom. The upper part is cylindrical, and made of wood hooped with iron; and the lower part is conical, and made partly of cast-iron and partly of sheet-iron.

B is the hot-blast pipe.

C C is an annular space in communication with the pipe B.

D D are two of twelve openings, 3" in diameter, in the floor of the space C C.

E is a slide by means of which the bottom may be closed or opened.

The apparatus is under cover, and supported by four brackets inserted in brick pillars. When the hot-blast is let on, the bottom being closed, it descends through the openings, D D, and thence rises through the mass of overlying peat. The drying goes on uninterruptedly, fresh peat being put in at the top as fast as dried peat is taken out at the bottom, where, it is obvious, the peat must be driest. From 20 to 40 cubic feet (1 Hanoverian linear foot = 0.958 English foot) of dried peat are withdrawn at a time. The peat is said to be uniformly dried by this process; and as it need not be withdrawn faster than it is required, there is no necessity for storing it and so enabling it to absorb moisture from the atmosphere. The dimensions of the apparatus may be varied according to the daily requirements, and that above described will, it is reported, evaporate in a day at least 20 per cent. of water from 20,000

lbs. (0.9 lb. = 1 lb. avoirdupois), or about 10 tons of peat (in its ordinary air-dried state, it is presumed, though it is not so stated), with a supply of 2000 feet of air per minute, heated to 100° C. and at ordinary atmospheric pressure. The temperature of the blast

⁴ The following description has been derived from a paper on the subject, illustrated with drawings, by Welkner, in the Berg- und hüttenmännische Zeitung for 1862, xxi. 221-225.

may be either increased or diminished, but if more rapid desiccation be desired, it is preferable to increase the quantity of blast rather than raise its temperature, lest the peat should ignite or become fissured. The cost of plant for the daily desiccation of 20,000 lbs. of air-dried peat, inclusive of special machinery for producing a fan-blast and of special apparatus for heating it, is stated to be 2500 Thaler, or about 375*l.*; but where a special engine for driving the fan is not needed, and hot-blast may be obtained by drawing air through pipes in the chimney of a furnace, the cost will be about half of that stated. The hot-blast may consist either entirely of atmospheric air or of a mixture of air and waste furnace-gas. The expense of working is alleged by the inventor to amount to only half of that attending the best systems of drying peat by artificial heat previously invented. Welkner's apparatus was adopted at the Alexis Smelting-works at Lingen, where a mixture of 47 per cent., in volume, of wood-charcoal and 53 per cent. of dried peat was used for smelting iron in blast-furnaces with, it is said, the most favourable results. The fan for supplying hot-blast to the drying apparatus at these works was driven by a steam-engine in operation for general purposes, of which the boiler was heated by the waste-gas of the blast-furnace, and the air for the drying apparatus was heated first by passing through a pipe arrangement in the boiler-furnace chimney, and afterwards only to a very small additional degree with a consumption of 5 per cent. of the dried peat consumed in smelting. Welkner contrasts his apparatus with Weber's drying-house, and contends for its superiority on the ground that more heat is abstracted from the air and turned to useful account than in the latter, in which at first much more water is evaporated than subsequently, though the same quantity of air heated to the same degree may be passing all the while; whereas on his system, with a pretty constant supply of wet peat at the top, the heated air cannot escape without having performed its due amount of work in the matter of evaporation. But Welkner is not the only person who has proposed the desiccation of peat by means of heated air, forced or drawn through a mass of peats by mechanical power; for Ekman's and other kilns, it will be remembered, are constructed on the same principle. There is, however, a difference in the mode of applying the principle, Welkner, for example, causing heated air to ascend, and Ekman causing it to descend, through the peat.

DESICCATION OF PEAT BY CENTRIFUGAL ACTION.

Machines have been invented for removing a considerable proportion of water in wet peat by centrifugal action; but, so far as I am aware, they have not proved successful in practice. Mr. Vignoles, the civil engineer, has described the following process for partially drying peat by this means.⁵ Peat in the state of pulp "is thrown in

⁵ Information on this subject has been derived from a pamphlet by Mr. Vignoles, respecting the Method and Cost of producing Coke from Turf. By Charles Vignoles, Civil Engineer, Member of the having the following title:—"Statements

mass into a cylindrical drum-shaped vessel, divided, if necessary, into compartments, which is caused to revolve with great rapidity upon its axis; the velocity requisite being such as shall drive off the water or other fluid from the solid parts of the peat or turf by centrifugal force." The axis of this cylindrical vessel should be placed vertically, and the cylinder should be from 6 to 10 feet in diameter, and from $1\frac{1}{2}$ to $2\frac{1}{2}$ feet in depth. The external surface of the cylinder is composed of fine wire-gauze, or of perforated sheet-metal, of which the apertures should be of such a size as to permit the water to pass through but not the particles of peat in any considerable degree. When the peat, as obtained from the bog, is not sufficiently pulpy, but "in a more consistent or fibrous condition," it may be readily reduced to the "state of a nearly homogeneous mud by the operation of edge-stones or of a pug-mill." As soon as the process for expelling the water has dried the peat into a coherent, consistent mass, it is removed and moulded into blocks.

M. Hebert, of Rheims, has also proposed a similar machine, in which peat is subjected to desiccation by centrifugal action and a current of heated air at the same time, and which, Vogel justly remarks, is more ingenious than practical.⁶

The difficulty to be overcome in such machines is to construct a sieve which will allow water freely to pass through it but none of the peat, and which will not become speedily stopped up; and further, it is essential that provision should be made for rapid filling and emptying. As yet no machine has been contrived which satisfactorily fulfils those conditions.

ON THE USE OF PEAT IN METALLURGICAL OPERATIONS IN SWEDEN.

My friend Gustaf Ekman has favoured me with the following notes regarding the use of peat in Sweden for metallurgical purposes in 1872.

The following descriptions of prepared peat are used:—

I. Pugmill-peat, prepared as described in the Jern-Kontoret's Annaler for 1858.⁷ In 1870, at Kolswa, 180,000 Swedish cubic feet (= 168,876 English cubic feet) were prepared, and delivered, air-dried and stacked, on the bog, at a cost of 0.034 Riksdaler per Swedish cubic

Royal Irish Academy; Fellow of the Royal Astronomical Society; Member of the Institution of Civil Engineers, &c. &c. London, 1850." It contains 47 pages and a lithograph of the apparatus, and was printed for private circulation at the time. Eight pages, beginning at p. 39, are devoted to the specification of a patent, with the heading, "Letters-Patent to Charles Vignoles, of Trafalgar Square, in the County of Middlesex, Civil Engineer, dated September 10, 1849, for 'An Improved Method of preparing or manufacturing Peat or Turf for Fuel.' (Communication.)" There is no mention

of this patent in the volume of Abridgments of Specifications relating to the Preparation and Combustion of Fuel, 1867; nor can the officers, at the Library of the Patent Office, find any record of such a patent.

⁶ A description of this machine, and an illustrative engraving, are given by Vogel in his volume on Peat, p. 83.

⁷ A translation of this paper was published, as already stated, in the Berg- und hüttenmännisches Jahrbuch, for 1860, xi. 95 *et seq.* The process is similar to those of Linning and others; see pp. 244, 245 *antea*.

foot (= 0.507 penny per English cubic foot). The grinding and moulding of the peat, in which steam was employed, cost $\frac{1}{2}$ of the above sum, and the labour for drying and stacking only $\frac{1}{4}$. It was intended, in 1872, to make 300,000 Swedish cubic feet (= 281,460 English cubic feet). The price of labour having risen about 50 per cent., the cost of the peat would be enhanced accordingly. To produce 300,000 Swedish cubic feet, about 100 men, women, and boys, working for three months, would be required.

The specific gravity of this kind of air-dried peat is nearly the same as that of water. 1 Swedish Centner (= 0.0417 English ton), when shovelled loosely in, will just fill the old Swedish measure called a "Tunna," which contains 6.3 Swedish cubic feet (= 5.91 English cubic feet), of which above one half, or 3.15 Swedish cubic feet (= 2.955 English cubic feet), may be calculated as interstitial space.

From 2.75 to 3 Swedish cubic feet (= from 2.58 to 2.81 English cubic feet) are required for heating 1 Centner of iron, in the reheating- or mill-furnace.

II. Cut-peat, which is extracted either (1) by machinery or (2) with the spade.

(1.) The peat is cut by machines of German invention, capable of raising the peat from a depth of from 14 to 16 Swedish feet (= from 13.7 to 15.7 English feet), below the surface of the bog. At Gryt, for a yearly production of 150,000 Swedish cubic feet (= 140,730 English cubic feet), 3 machines are employed, with 3 men for each machine, and from 12 to 15 women and boys for the drying, etc. 1 Swedish cubic foot of air-dried peat, delivered on the bog, costs about 0.02 Riksdaler (= 0.3 penny per English cubic foot).

(2.) At Skultuna, for copper- and brass-works, peat cut by a spade is used. 1 Swedish cubic foot delivered, stacked up, on the bog, costs 0.0125 Riksdaler (= 0.19 penny per English cubic foot), and weighs 18 Swedish lbs. (= 16.88 lbs. av.), whereas the same peat, treated in a pug-mill, weighs as much as 38 Swedish lbs. (= 35.63 lbs. av.).

At all the places above named, when peat is applied to the reheating of iron, a furnace on Siemens' regenerative principle is used, the gaseous fuel of which is produced by burning the peat in a gas-generator, in connection with one of Lundin's condensers. The wet condensers, however, as they are found to foul the water in streams and lakes, will now be exchanged for surface condensers.

The cut-peat is difficult to use alone for reheating iron, and is therefore usually mixed with twigs, pugmill-peat, sawdust, etc.

During the preceding year several limited companies had been formed for manufacturing spheroidal peat, a modification of pugmill-peat, intended for household use and other purposes. The product will be less liable to break and fall to pieces, but the cost of production will be considerably greater than that of the other kinds of peat.

A decided improvement in the manufacture of pugmill-peat is to form it into cylinders, 15 or 16 inches long, pierced lengthwise by

1, 2, or 3 holes, whereby the drying is remarkably accelerated. This method, invented by Mr. Samuelsson, is being more and more largely adopted, but is not used at Kolswa.

Lundin's condenser, mentioned by Ekman, is an apparatus by which gaseous fuel charged with aqueous vapour is exposed, in its course to the furnace, to a series of descending jets of water, whereby the moisture in the gaseous fuel is in great measure condensed and separated. In using sawdust for the production of such gaseous fuel, Lundin's condenser is reported to have been successfully applied in Sweden.

COAL.

In the year 1853 a remarkable trial took place at Edinburgh before the Lord Justice-General and a special jury, to try the question, "WHAT IS COAL?" The owners of an estate at Torbanehill, in the county of Linlithgow, had granted a lease of the whole coal, ironstone, limestone, and fire-clay contained within it, except copper, and any other minerals whatsoever than those above specified; and it should be remarked, that the true Coal-measures, of geologists, were proved to exist under the same estate. In the course of working, the lessees extracted a combustible mineral of great value as a source of coal-gas, and realized a large profit by the sale of it as gas-coal. The lessors, thereupon, denied that the mineral in question was coal, and disputed the right of the lessees to work it. At the trial there was a great array of scientific men on each side, including chemists, botanists, geologists, and microscopists; and of practical gas-engineers, coal-viewers, and others, there were not a few. On the one side it was maintained that the mineral was *coal*, and on the other that it was a *bituminous schist*. The evidence, as might be supposed, was most conflicting. The judge, accordingly, ignored the scientific evidence altogether, and summed up as follows:—"The question for you [the jury] to consider is not one of motives, but what is this mineral? Was it coal in the language of those persons who deal and treat with that matter, and in the ordinary language of Scotland? *because, to find a scientific definition of coal after what has been brought to light within the last five days, is out of the question.* But was it coal in the common use of that word, as it must be understood to be used in language that does not profess to be the purest science, but in the ordinary acceptance of business transactions reduced to writing? Was it coal in that sense? That is the question for you to solve, for you to determine." The jury found that it was coal.¹ Subsequently

¹ A full Report of the Trial before the Lord Justice-General and a Special Jury of the Issues in the Action and at the Instance of Mr. and Mrs. Gillespie of Torbanehill against Messrs. Russel and Son, Coal-masters, Blackbraes, for Infringe-

ment of Lease of Coal and Ironstone, etc. Edinburgh, 1853. A second trial took place, when a fresh issue was raised, and large damages were awarded to the lessors. The report is both instructive and amusing, and will well repay perusal.

to this trial the same mineral was pronounced *not to be coal* by the authorities of Prussia, who accordingly directed it not to be entered by the custom-house officers as coal.²

From what precedes, it is evident that it is not easy to frame a precise definition of the term coal, either in a commercial or in a scientific sense. Some of the substances to which the term coal is applied differ widely from each other both in physical and chemical characters. Coal is the product of the decomposition of vegetable matter under special conditions, and in various degrees. Thus, at the one extreme is lignite, some varieties of which resemble wood in appearance, and approximate to peat in composition; and at the other is anthracite, which consists almost wholly of carbon, and is, in all respects, unlike wood. Again, the proportion of earthy matter, or ash, in coal is subject to great variation. Suppose a mineral to consist of 5 per cent. of black, coal-like, combustible matter, similar in composition to undoubted coal, and of 95 per cent. of earthy matter, no one would designate such a mineral as coal. Then the question arises, what is the *maximum* amount of such matter which can exist in coal? No definite answer can be given, and no exact and unexceptionable definition of the term coal has as yet been constructed. Geological position does not afford satisfactory grounds for a precise definition, for the mineral which was the subject of investigation at the trial in Edinburgh occurs in association with undoubted coal of the Carboniferous system; and coal, possessing the same chemical and physical characters as the coal of that system, is met with in other and more recent geological formations. Perhaps a near approach to a definition would be the following:—Coal is a solid, stratified, mineral, combustible substance, varying in colour from dark-brown to black, opaque except in extremely thin slices, brittle, not fusible without decomposition, not sensibly soluble in ether, benzole, chloroform, or oil of turpentine, not containing sufficient earthy matter to render it incapable of being applied with advantage as a source of heat either in ordinary fireplaces or in furnaces. This would exclude amber and other resinous matters, bitumen, and bituminous schists containing so large an amount of earthy matter as to be incapable of being employed as fuel; but it would not exclude some of the most compact varieties of peat, which are black, brittle, and exhibit a conchoidal fracture.

My friend Dr. Bennett repudiates the verdict of the Scotch jury, and thus writes: "At the trial it was very plausibly argued that, in a bargain between man and man, scientific truths were of no value, and that a whale among whalers was still a fish. But as no naturalist, conversant with the structure and functions of a whale, would for a moment suppose it to be a fish because it inhabits the water and resembles one, so, I contend, no histologist acquainted with the structure and properties of the Torbanehill mineral ought to maintain that it is coal because it is dug out of the earth and burns in the fire." Dr. Bennett has proposed a seemingly arbitrary definition of coal

² Wagner's Jahresbericht, 1857, iii. 499.

founded on the appearance, under the microscope, of certain rings in a well-made transverse section, and maintains that by means of this appearance all kinds of coal, whether household or cannel, can at once be distinguished from the Torbanehill mineral.³ These rings appear to be the remains of the macro-spores of Williamson, or of the spore-cases of other observers (see p. 269), and their significance with respect to the definition of coal will be presently considered in a notice on the Microscopic Examination of Coal.

ORIGIN AND FORMATION OF COAL.

Whatever difference of opinion there may be respecting the mode of accumulation of the great deposits of coal, whether they have, like peat, been produced *in situ*, or have been derived from drift-wood, there can be no doubt that coal has been produced from vegetable matter, though perhaps not exclusively and universally in the literal sense of those terms. We can readily select a series of coals of which the composition will exhibit the gradual passage of vegetable matter into anthracite, or that variety of coal which consists almost wholly of carbon. Such a series is presented in the following tabular form, the proportion of carbon being estimated at the constant amount of 100:—

TABLE SHOWING THE GRADUAL CHANGE IN COMPOSITION FROM WOOD TO ANTHRACITE.

| Substance. | Carbon. | Hydrogen. | Oxygen. | Disposable Hydrogen. ⁴ |
|---|---------|-----------|---------|-----------------------------------|
| 1. Wood (the mean of several analyses)..... | 100 | 12·18 | 83·07 | 1·80 |
| 2. Peat (ditto ditto)..... | 100 | 9·85 | 55·67 | 2·89 |
| 3. Lignite (ditto, of 15 varieties) | 100 | 8·37 | 42·42 | 3·07 |
| 4. Ten-Yard coal of the South Staffordshire basin | 100 | 6·12 | 21·23 | 3·47 |
| 5. Steam coal from the Tyne | 100 | 5·91 | 18·32 | 3·62 |
| 6. Pentrefelin coal of South Wales | 100 | 4·75 | 5·28 | 4·09 |
| 7. Anthracite from Pennsylvania, U. S. | 100 | 2·84 | 1·74 | 2·63 |

From an inspection of the table it will be perceived that, through the various stages of conversion therein set forth, the proportion of carbon relatively increases while that of the hydrogen and oxygen relatively decreases; and that in the relation between the hydrogen and oxygen, except in the case of anthracite, there is a steady increase in the proportion of disposable hydrogen, or that in excess of the amount required to form water with the oxygen present.

The formation of coal from vegetable matter may, like that of peat (see pp. 213 *et seq.*), be explained by the elimination of hydrogen in combination with carbon as *marsh-gas*, of oxygen in combination with carbon as *carbonic acid*, and of hydrogen in combination with

³ An Investigation into the Structure of the Torbanehill Mineral and of various kinds of Coal, by John Hughes Bennett, M.D., F.R.S.E. Trans. of the Royal Soc. of Edinburgh, 1854, xxi. (part i.) 173.

⁴ See p. 156 *supra*.

oxygen as *water*.⁵ That the derivation of coal from vegetable matter has been accompanied with the evolution of marsh-gas might be inferred from the nature of the gases generally occurring in coal-mines, of which that gas is a constituent. However, the hydrogen and oxygen are never completely separated, and are always present in sensible proportion even in anthracite, which is furthest removed in composition from vegetable matter.

MICROSCOPIC EXAMINATION OF COAL.*

In recent years coal of different kinds and from various localities has been the subject of microscopic examination by several observers, who affirm that the seed-vessels, termed spore-cases, of lycopodiaceous plants constitute nearly the entire mass of some varieties of coal, and a greater or less proportion of that of coal in general. Hence it has been inferred that the theory of the derivation of coal from vegetable tissue and the matters naturally associated therewith is erroneous, and that the formation of it has not been similar to that of peat. On the other hand, Williamson maintains that what have been regarded as spore-cases are only larger spores or macro-spores, and that these bodies have played a much more limited part than has been assigned to them, in the formation of coal.

Although the full consideration of this interesting question would be out of place in a treatise on Metallurgy, yet the few following remarks upon it may not be irrelevant. The number and variety of the coals hitherto investigated microscopically are insufficient to justify a general and decided induction concerning the origin of coal, even though the spore-cases or macro-spores had been found to exist abundantly in every specimen; but the fact is that in some kinds of coal they constitute only a small proportion of the mass, while from others they are entirely absent. Thus, it is asserted by Dawson, who has devoted special attention to the microscopic structure of coal, and who has seen even Pennsylvanian anthracite full of the so-called spore-cases, some of them retaining their round form and filled with granular matter which might represent the spores, that "sporangite beds are exceptional among coals, and that cortical and woody matters are the most abundant materials in all the ordinary kinds;" but it should be added that his investigation seems to have been restricted to North American coals, and not to have extended to those of England. Yet as it has been demonstrated that the Coal-measures of both countries are of the same geological

⁵ Liebig's Chemistry in its Application to Agriculture and Physiology. Edited by Playfair; 2nd edition, 1842, p. 350. Also, Bischof's Lehrbuch der chemischen und physikalischen Geologie, 1st edition, ii. 1780.

* For information on this subject see a paper "On Spore-cases in Coals," by J. W. Dawson, LL.D., F.R.S., in the

American Journal of Science and Arts, s. 3, 1871, i. 256-263: also an interesting lecture by Professor W. C. Williamson, on "Coals and Coal Plants," delivered before the British Association at Bradford, and reported in *The Bradford Observer*, Sept. 20, 1873, in which the question of the alleged formation of coal from spores and spore-cases is discussed.

age, and abound in the remains of plants, which belong to the same natural families, and for the most part to the same or nearly allied genera, such as *Lepidodendron* and *Sigillaria*, it might be anticipated that there would be similarity in the structure of American and English coal; and, indeed, I have a microscopic section of Carboniferous coal from the New Battle Colliery, near Dalkeith, in Scotland, which was cut by the late George Sanderson of Edinburgh, in which the structure of woody tissue may be distinctly seen.

When we consider how much variation there is in the physical characters of vegetable tissue, especially in compactness, and that the tissue of some plants is impregnated with resinous substances, which have resisted decomposition under the conditions attending the formation of coal, it is easy to conceive why the original structure of that tissue should, during its conversion into coal, be more likely to be preserved in some cases than in others; for, in proportion to the resistance of a part to decomposition, under those conditions, is the probability of the perpetuation of the structure of that part. Of the resinous substances which probably have undergone little or no change, though exposed to conditions favourable to decomposition during considerable periods of geological time, may be mentioned amber, which occurs in the brown-coal of Greenland, and resin, sometimes in lumps larger than a hen's egg, in the coal of the Island of Labuan. These substances had, doubtless, exuded from some of the plants, out of which the accompanying coal has been derived, just as many resinous matters exude and drop from the stems of existing plants of particular kinds.

The material named lycopodium or vegetable brimstone, which, on account of its igniting easily and burning with a bright flame, is used at theatres for producing sham lightning, and has also been applied as a coating for pills in order to render them impermeable to moisture, consists of the spores of *Lycopodium clavatum* and *L. Selago*.⁷ It has been found to have the following composition per cent., and for the sake of comparison the composition of pure cellulose and of cork is also inserted:⁸—

| | <i>Lycopodium.</i> | Cellulose. | Cork. |
|----------------|--------------------|---------------|---------------|
| Carbon | 64.80 | 44.44 | 65.73 |
| Hydrogen | 8.73 | 6.17 | 8.33 |
| Nitrogen | 6.18 | — | 1.50 |
| Oxygen | 20.29 | 49.39 | 24.44 |
| | <u>100.00</u> | <u>100.00</u> | <u>100.00</u> |

⁷ The Vegetable Kingdom, Lindley, 1847, p. 70.

⁸ From Dawson's paper previously quoted, in the American Journal of Science and Arts, s. 3, 1871, i. 262. The analysis of the lycopodium was made by Ducom, and is reported in Liebig and Kopp's Jahresbericht for 1847-8, p. 829; that of cellulose was by Payer and

Mitscherlich, and is reported in Payen's Mémoires sur les Développements des Végétaux, p. 234; and that of the suberin of cork (*Quercus Suber*) is extracted from Gmelin's Handbook, xv. 145. Mr. E. T. Newton, Assistant-Naturalist of the Geological Survey, informs me that he has examined commercial lycopodium and found it to be free from spore-cases.

From the large relative proportion of hydrogen in lycopodium spores, and from their inflammability, it is probable that they contain resinous matter, which may have tended to preserve their structure; but whether the spore-cases differ in composition from the spores, I am unable to state. Now, if we admit that coal does, in some instances, consist mainly of such macro- and micro-spores (the former being the spore-cases of some observers), it may be asked whether those bodies were originally mixed with other vegetable material, which, during the formation of such coal, has either wholly or in great measure disappeared; or, whether they may not have been accumulated in enormous masses over large areas by the long-continued action of wind or water, or of both. This hypothesis of accumulation might probably explain the origin of some beds of coal rich in hydrogen, such as cannel coal, and especially the very local occurrence of such coal in association and sometimes in actual contact with ordinary so-called bituminous coal. In considering this subject, it should be borne in mind that we have *geological time* at our disposal, and, consequently, no difficulty in accounting for the magnitude of a result by the operation of causes apparently inadequate. While, however, there may be grounds for accepting the hypothesis in question with respect to the origin of coal in a few particular instances, there are none to justify its application to coal in general.

Another argument in support of the generally accepted theory of the origin and formation of coal, may be adduced from what has been established concerning the origin of peat. As the vegetable tissue of certain mosses and other plants is capable of producing at the present time such a substance as pitch-peat, which closely resembles certain varieties of coal, both in physical characters and chemical composition, why, it may be asked, should the tissues of the plants existing in the Carboniferous era be supposed to have been incapable of producing coal, seeing that the laws of Nature are constant and uniform in their operation? Again, coal occurring in geological formations posterior to the Carboniferous, often abounds to such an extent in the impressions of the leaves of phænogamous plants as to lead to the inference that it has been derived exclusively or nearly so from such vegetable material. In conclusion, I may state that I have met with no evidence sufficient to convince me that the generally received theory of the origin and formation of coal is erroneous.

GEOLOGICAL AGE OF COAL NOT ASCERTAINABLE FROM PHYSICAL AND CHEMICAL CHARACTERS.

Zincken has shown that even the lignite or brown-coal of the Tertiary formations cannot always be distinguished from coal of earlier geological date, by physical and chemical characters, and the following remarks, which he has made upon this subject, should be attentively read:—"There are no physical and chemical properties by which in all cases a coal may be characterized as brown-coal and distinguished from other kinds of coal. Coals from different formations are sometimes so

similar in external characters, as to be confounded with each other. Thus, for example, at Malowka, in Russia, a Carboniferous coal has been found which in parts wholly resembles brown-coal in appearance, and moreover a comparatively recent one, so that it was only by accurate scientific investigation proved to belong to the Carboniferous system. There is coal from the Cretaceous formation, which appears to be identical with certain kinds of brown-coal; and there is alluvial coal, nay, even peat, which exactly resembles varieties of brown-coal. Hence, the relative age of a coal can only be determined by the geological and palæontological conditions of its formation."⁹

According to Frémy, the varieties of lignite termed *bituminous wood* are, like peat, only partially soluble in an aqueous solution of potash or soda, but dissolve almost entirely in nitric acid and aqueous solutions of hypochlorites. The compact and black varieties of lignite, resembling bituminous coal, are in general not acted upon by alkaline solutions, but dissolve completely in hypochlorite solutions as well as in nitric acid. On the other hand, according to the same observer, bituminous coals do not dissolve either in alkaline solutions or in hypochlorites. But both bituminous coals and anthracite dissolve completely in a mixture of monohydrated sulphuric acid and nitric acid; a dark-brown solution is produced, containing an *ulmic* compound, which is entirely precipitated on the addition of water.¹ Experiments on this subject have been made in my laboratory, the results of which are recorded on p. 300.

Kremers asserts that while the product of the dry distillation of brown-coal always contains acetic acid, partly free and partly in combination with ammonia, other coals contain none in either state, but yield free ammonia; whereas Zincken maintains that this property neither belongs to all brown-coals nor to all other coals.²

WATER IN COAL.

All coal contains a greater or less proportion of water, which may be expelled at or slightly above 100° C. A coal may appear perfectly dry and yet lose by such desiccation a comparatively large amount of water, as much even as 20 per cent. in the case of some lignites. Whether the water exists wholly as hygroscopic water, or whether, in some cases, it may not be partially combined, is doubtful. When freshly-won coal is left exposed to the air, it loses one part of the water by evaporation, but retains another part. The former has been designated pit-water, and the latter hygroscopic water. By pit-water is meant water in the ordinary liquid state with which the coal is wetted, and by hygroscopic water that which exists in it in the same state as water in air-dried wood. When coal

⁹ Die Physiographie der Braunkohle, p. 5.

¹ Comptes rendus, 1861, lii. 114.

² Op. cit. p. 5. See also the thesis of

Kremers, De relations inter carbonées fuscas atque nigres, Berlin, 1851, p. 18; and the list in the sequel of the compounds formed in the dry distillation of coal.

is desiccated at or somewhat above 100° C., it loses, as previously stated, the whole of its water; but when, after this treatment, it is allowed to remain in contact with the atmosphere, it absorbs water from the latter, but not so much as it originally contained. The water which was present in the state of pit-water will not be thus re-absorbed by the coal; and in support of this proposition the following evidence is adduced. A large lump of air-dried coal from Lower Silesia was found to lose 4·31 per cent. of hygroscopic moisture by desiccation at 105° C., while the same coal in particles of the size of linseed lost by the same treatment 3·92 per cent. The two parcels of coal were then put into a cellar, where the temperature was 8° C., and there left until they ceased to gain in weight, which occurred after the lapse of 36 hours, when it was found that the lump had increased 0·74 and the fine coal 0·83 per cent. in weight. They were again dried at 105° C., when the lump lost 0·63 and the fine coal 0·79 per cent. in weight; and by a second exposure to the air and subsequent desiccation, the former increased about 0·52 and lost 0·55, and the latter increased about 0·80 and lost 0·81 per cent. in weight. The tendency of the dried coal to attract moisture was thus reduced nearly 0·2 per cent. by repeated desiccation, and in proportion to the diminution in hygroscopic quality the coal became more tender and friable.³ Different kinds of coal differ much from each other in their hygroscopic capacity, and the quantity of water absorbed by any kind of coal from the atmosphere will vary with the degree of moisture of the latter, and with the temperature, as well as with the state of division of the coal. In the following table are given Grundmann's results on the proportions of water in the fine slack and lumps of six kinds of Carboniferous coal from Upper Silesia, as they came from the pit, and after exposure to the air during 36 hours :⁴—

TABLE SHOWING THE PROPORTION OF WATER IN FINE SLACK AND LUMP COAL FROM UPPER SILESIA.

| No. | Moisture per cent. in the Fine Slack (<i>Staubkohle</i>) as it came from the pit. | Moisture per cent. in the Fine Slack after Exposure to the Air during 36 Hours. | Pit-Water per cent. in the Fine Slack. | Moisture per cent. in the Lump Coal as it came from the Pit. | Moisture per cent. in the Lump Coal after Exposure to the Air during 36 Hours. | Pit-Water per cent. in the Lump Coal. |
|-----------|---|---|--|--|--|---------------------------------------|
| I | 7·036 | 5·887 | 1·149 | 6·774 | 3·050 | 3·724 |
| II | 7·442 | 4·887 | 2·555 | 8·078 | 3·786 | 4·287 |
| III | 5·996 | 4·210 | 1·786 | 5·264 | 2·069 | 3·195 |
| IV | 6·798 | 5·332 | 1·457 | 6·566 | 2·048 | 4·518 |
| V | 8·246 | 6·332 | 1·914 | 9·000 | 3·841 | 5·159 |
| VI | 7·137 | 5·489 | 1·648 | 6·449 | 2·497 | 3·952 |

By subtracting the loss by exposure from the quantity of water originally present, the proportion of what is termed pit-water is found, which is represented by that loss. It will be noticed that in

³ Die Steinkohlen Deutschlands und anderer Länder Europas, etc., by Geinitz, Fleck, and Hartig, Professors at the Royal Polytechnic School, Dresden, 1865, ii. 215.

⁴ Ibid. p. 216.

every instance the fine coal contained less pit-water than the lump coal, which might have been anticipated; for it is obvious that by the division of the coal, evaporation of the imprisoned *liquid* water must be promoted. But, on the other hand, the hygroscopicity of the coal is increased by such division and in a degree corresponding to its fineness. Hence, different-sized particles of the same air-dried coal will contain different proportions of water, and this is a point which should be considered in the quantitative estimation of water in coals; but it should also be borne in mind that in expelling the whole of the water by drying at or a little above 100° C., not only occluded gas, but volatile products, besides water, may possibly be evolved (see p. 282). In experiments to ascertain the calorific value of coal, attention should also be directed to the same point, i.e. the variability of the proportion of water in coal under the conditions above mentioned.

The amount of water which may remain in some varieties of coal, even after desiccation by free exposure to the air, deserves more attention than it generally receives from metallurgists.

It should, however, be stated that in certain cases advantage is said to result from wetting coal before burning it. Thus it has been asserted that when the dry fine slack (*Staubkohle*) of a caking coal is used in heating steam-boilers, the fine particles, as soon as they are thrown on the fire, evolve their gaseous constituents, and become converted into small bright globular particles of coke, which may drop unburnt into the ash-pit, or accumulate and clog the bars, so causing irregularity in the process of combustion; and it is further asserted that this evil is lessened by previously wetting the slack. Although, therefore, wetting must reduce the calorific power of the coal—since the water added must be evaporated—yet the latter evil may be less than the former; in which case, if wetting is really efficacious in diminishing the evil, advantage might clearly result from this treatment. But, as no accurate experimental data have been advanced, it would be useless to consider the subject further.

NITROGEN IN COAL.

Nitrogen, in a state of chemical combination, is always found in coal, and its proportion seems to range pretty constantly between 1 and 2 per cent. Nitrogenous matters are always associated with cellulose, so that the presence of nitrogen in coal is readily accounted for.

SULPHUR IN COAL.

Sulphur is always present in coal. It may exist in the state of sulphuric acid in combination with a base; in combination with iron as iron-pyrites or bisulphide of iron; and, doubtless, also in combination with the organic elements of coal, as it exists, for example, in hair. It chiefly occurs in the state of iron-pyrites, from which no coal is entirely free, and which may occur either disseminated through the mass so as to be invisible, or in con-

spicuous though very thin brass-yellow-coloured laminæ, often of high metallic lustre, or in layers and nodules sometimes of considerable dimensions. In the dry distillation of coal a portion of the sulphur is evolved as sulphuretted hydrogen and bisulphide of carbon. In the following table are shown the proportions of sulphur evolved in the burning of coal and retained in the ashes :⁵—

TABLE SHOWING THE PROPORTIONS OF SULPHUR EVOLVED IN THE BURNING OF COAL AND RETAINED IN THE ASHES.

| Coals of the Carboniferous System. | Ash in 100 Pounds of Coal. | Sulphur in 100 Pounds of Coal. | Sulphur in 100 Pounds of Ash. | Sulphur in the Ash from 100 Pounds of Coal. | Sulphur evolved in burning 100 Pounds of Coal. |
|------------------------------------|----------------------------|--------------------------------|-------------------------------|---|--|
| | Pounds. | Pounds. | Pounds. | Pounds. | Pound. |
| From Zwickau | 7·360 | 0·789 | 9·464 | 0·696 | 0·093 |
| From do. | 5·760 | 0·973 | 14·663 | 0·844 | 0·129 |
| From Berthelsdorf ... | 16·530 | 3·264 | 18·174 | 2·424 | 0·840 |
| Anthracitic coal from Fölsch | 48·316 | 1·746 | 2·798 | 1·352 | 0·394 |

In the sequel (see p. 344), analytical evidence will be given in support of the above statement, that sulphur is present in some varieties of coal in what may be designated a state of organic combination; but what the definite compound may be which contains it is unknown. Now, Church has described and analysed a sulphuretted combustible mineral, for which it is desirable search should be made in those varieties of coal containing sulphur in the last-named state of combination. It was shown in the Tasmanian Court of the International Exhibition in London, in 1862, and designated as “resiniferous shale.” Its physical and chemical characters are stated to be as follow :—it is solid, translucent, reddish-brown, conchoidal in fracture and resinous in lustre; its specific gravity is about 1·18, and its hardness = 2; it burns in the air with a fetid smoky flame, fuses by heat, and yields oily and solid products having a disagreeable smell, suggesting that of some kinds of Canadian petroleum; it is not acted upon by hydrochloric acid, but is slowly oxidized by nitric acid with the evolution of carbonic acid and nitric oxide, and the formation of sulphuric acid; it is readily carbonized by sulphuric acid, but is not acted upon by aqueous alkaline solutions, and is not dissolved in the least degree by alcohol, ether, benzole, oil of turpentine, paraffin oil, or bisulphide of carbon. Church has given the name of *tasmanite* to this mineral, the composition of which is as follows :—

COMPOSITION OF TASMANITE.

| | |
|------------------------------|---------------|
| Carbon | 79·34 |
| Hydrogen | 10·41 |
| Sulphur | 5·82 |
| Oxygen (by difference) | 4·93 |
| | <u>100·00</u> |

⁵ Die Steinkohlen Deutschlands und anderer Länder Europas, etc., 1865, ii. 220.

Church suggests that rock-oils may have, in some cases, been produced by the action of heat upon substances similar to this Tasmanian mineral.⁶

PHOSPHORUS IN COAL.

Attention has recently been directed by Le Chatelier and Léon Durand-Claye⁷ to the presence of phosphorus in notable quantity in the ashes of coal. As might have been anticipated, it is found to exist in the state of phosphoric acid, combined with one or more of the bases usually present in such ashes. In several analyses of the ashes of Welsh and Scotch coals, published in the first edition of this work, phosphoric acid appears as a constituent, varying in quantity from 0.21 to 3.01 per cent. of the ashes. The authors above named, have added analyses of the ashes of coals from France and the United States, in which phosphoric acid has been quantitatively determined: these analyses will be found in the sequel at pp. 352, 353. Mr. J. Blodget Britton⁸ has estimated the quantity of phosphorus in many samples of Pennsylvanian anthracite, and found it to vary from a trace up to about 1.4 per cent. of the ashes, which in this sample constituted 5.39 per cent. of the coal.

The subject is clearly one of great practical importance in reference to iron-smelting, when it is desired to produce pig-iron containing as little phosphorus as possible; such, for example, as is requisite for the Bessemer process of steel-making. It has been demonstrated, that in the large modern blast-furnace for smelting iron, practically, the whole of the phosphorus, existing in the state of phosphate in the ores treated, passes into the pig-iron, except in the case of imperfect reduction; and it is more than probable, that any phosphorus, existing in the coal or coke used, will similarly pass into the pig-iron.

METALS OCCASIONALLY PRESENT IN COAL.

Daubrée found from 0.08 to 0.2 per cent. of arsenic in ordinary specimens of lignite from the Tertiary strata, at Lobsann, Lower Rhine; 0.003 per cent. in the Carboniferous coal of Saarbrück; 0.0415 per cent., besides traces of antimony and copper, in coal occurring at Villé, Bas-Rhin, in France; and he detected traces of arsenic and antimony in coal from Newcastle-on-Tyne.⁹ Dr. Angus Smith discovered arsenic in the iron-pyrites of fifteen specimens of Lancashire coal and of a few others.¹ Dugald Campbell found arsenic, and in one or two instances copper, in the iron-pyrites of

⁶ On Tasmanite, a new Mineral of organic Origin. By Arthur H. Church, B.A. Oxon., Professor of Chemistry, Royal Agricultural College, Cirencester. *Phil. Mag.*, s. 4, 1864, xxviii. 465.

⁷ Note sur la Présence du Phosphore dans les Cendres de la Houille. From the Bulletin de la Société d'Encourage-

ment pour l'Industrie Nationale. Paris, 1873.

⁸ Trans. of the American Institute of Mining Engineers, 1871-1873, i. 298.

⁹ Ann. des Mines, s. 5, 1858, xiv. 472: s. 4, 1851, xix. 669.

¹ *Phil. Mag.*, s. 4, 1860, xx. 408.

coal.² In my laboratory decided traces of arsenic have been detected in a coal from Nottinghamshire, and of copper in anthracite from South Wales. I have a specimen of coal from Bedworth, in Warwickshire, which contains galena in a concretionary form, and I am indebted to Lord Wharnccliffe for beautifully crystallized specimens of the same mineral imbedded in coal from Yorkshire, and to the late Mr. Ebenezer Rogers for a specimen of galena in a thin vein of crystallized carbonate of lime, which traversed a coal-seam at Abercarn, in South Wales. The British coals above mentioned all belong to the Carboniferous system.

FIBROUS AND GRANULAR MATTER IN COAL: MOTHER OF COAL
(*Russkohle* or *Faserkohle*, German).

In some kinds of coal may often be observed thin layers or patches of black, fibrous, soft matter, which soils the fingers, and is much like wood-charcoal in appearance. It is met with in cannel coal, but in less quantity than in other kinds of coal. Under the microscope it is found to possess the structure of woody tissue.³ A granular and more or less pulverulent variety of this matter also occurs in coals. Dr. Rowney has examined both kinds, and finds them to differ sensibly in composition from the coal with which they are associated. Both kinds exist in coal of the Carboniferous series, but only the fibrous kind is mentioned as present in coal of the Oolitic formation and Tertiary series. Rowney describes the pulverulent kind as occurring sometimes as a light powder, and at others as a cindery substance which peels off the coal in flakes, easily reducible to powder; his analyses of these substances are as follow:—

COMPOSITION, PER CENT., OF FIBROUS AND GRANULAR MATTER IN COALS, DRIED AT 100° C.

| No. | Character. | Carbon. | Hydrogen. | Oxygen. | Nitrogen. | Ash. |
|------|----------------|---------|-----------|---------|-----------|-------|
| I. | Fibrous | 82·97 | 3·34 | 6·84 | 0·75 | 6·08 |
| II. | Granular | 72·74 | 2·34 | 5·83 | | 19·08 |
| III. | Fibrous | 73·42 | 2·94 | 8·25 | | 15·39 |
| IV. | Do. | 74·71 | 2·74 | 7·67 | | 14·86 |
| V. | Do. | 81·17 | 3·84 | | 14·98 | |

I. From the common household coals of the Glasgow coal-fields. II. From the Stonelaws coals. III. From Ayrshire coal. IV. From the splint coal, Elgin colliery, Fifeshire. V. From the Five-foot seam, Elgin colliery, Fifeshire.⁴ The composition of the coals, as determined by Rowney, from which III., IV., and V. were taken, will be found in the table, p. 325, Nos. 33–35.

² Phil. Mag., s. 4, 1860, xx. 304.

³ Dr. Bennett, Trans. of the Royal Soc. of Edinburgh, 1854, ii. 186.

⁴ Edinburgh New Phil. Journ. 1855, ii. 141.

ASHES OF COAL.

All coal contains a sensible amount of so-called inorganic matter, of which the chief constituents are silica, alumina, lime, and oxide and bisulphide of iron. It is this matter from which the ashes of coal are formed. Now, as alumina is not an ordinary constituent of plants, it follows that this matter has been derived, not merely from the inorganic elements originally existing in the plants from which coal has been produced, but also from an extraneous source. When we consider the conditions under which coal is believed to have originated, we can be at no loss to understand how such extraneous matter may have been carried into a coal-field by the agency of water and probably also of wind. We have only to inspect a coal-seam to have ocular and positive proof of the interstratification of coal and earthy matter such as shale and sandstone. In illustration we may take the familiar but extreme case of blackband ironstone. This ironstone consists essentially of carbonate of iron intimately mixed with coal. If further proof were needed of the admixture of coal with such extraneous matter, it is furnished conclusively by the results of Taylor, who has analysed the matter forming the bed and the roof of a coal-seam at Newcastle (Buddle's Hartley and Blaydon Burn Collieries), as well as the ashes of the intervening coal. The analyses are as follow: ⁵—

TABLE SHOWING THE COMPOSITION OF THE INORGANIC MATTER OF THE BED AND ROOF OF A COAL-SEAM AND OF THE ASHES OF THE INTERVENING COAL.

| Constituents per cent. | I. | II. | III. | IV. | V. |
|---------------------------|--------|--------|--------|-------|-------|
| Silica | 62·44 | 59·56 | 64·21 | 56·51 | 58·99 |
| Alumina | 31·22 | 12·19 | 28·78 | 31·89 | 26·19 |
| Sesquioxide of iron | 2·28 | 15·96 | 2·27 | .. | 5·14 |
| Protoxide of iron | .. | .. | .. | 7·04 | 5·11 |
| Lime | 0·75 | 9·99 | 1·34 | 1·69 | 0·67 |
| Magnesia | 0·85 | 1·13 | 1·12 | 0·85 | 1·54 |
| Potash | 2·48 | 1·17 | 2·28 | 1·38 | 2·34 |
| Soda | .. | .. | .. | 0·61 | .. |
| Total | 100·00 | 100·00 | 100·00 | 99·97 | 99·98 |

I. *Fire-clay*, on which the coal rests, after subtraction of 10·5 per cent. of water and 0·44 per cent. of chloride of sodium and sulphate of soda. II. Ashes (1·36 per cent.) of *good coal*, after subtraction of 8·2 per cent. of sulphuric acid. The presence of so large a quantity of sulphuric acid will be explained in the sequel (see p. 301). III. Ashes (16·9 per cent.) of *coarse coal*, after subtraction of the sulphuric acid.

⁵ Edinburgh New Phil. Journ. 1850-1, | chemischen und physikalischen Geologie,
1. 140 *et seq.* Bischof's Lehrbuch der | 1st edition, ii. 1771.

IV. *Bituminous shale*, after subtraction of 39·35 per cent. of organic matter. V. *Blueish shale*, after subtraction of 11 per cent. of water.

In exemplification of the occurrence of a large intermixture of coal in shale, or of shale in coal, the following analysis is inserted of a black shale from the High Delf Colliery, Gloucestershire: it was made by C. Tookey in my laboratory in 1864:—

COMPOSITION, PER CENT., OF BLACK SHALE.

| | | Exclusive of Sulphur, Ash, and Water. |
|---------------------------|--------|--|
| Carbon | 51·61 | 83·58 |
| Hydrogen | 3·27 | 5·29 |
| Oxygen and nitrogen | 6·87 | 11·13 |
| Sulphur | 2·60 | — |
| Ash | 31·40 | — |
| Water | 4·25 | — |
| | 100·00 | 100·00 |

The colour of the ash was brown, and in burning the shale evolved sulphurous acid.

MICROSCOPIC EXAMINATION OF THE ASHES OF COAL.

Mr. J. B. Dancer, of Manchester, has observed and described a singular structure in the ash or dust from the flue of a steam-boiler furnace in which common engine-coal was used as fuel.⁶ It was reddish-brown, and free from carbonaceous matter. When magnified 40 or 50 diameters, it was found to consist of ferruginous matter and crystallized substances, some particles of it being transparent, others white and red. It contained also singular objects, which varied considerably in size and colour, and of which the majority were spherical; and when separated from the irregularly-shaped particles forming the bulk of the dust, some of them had a brilliant polish, and appeared to be as perfect in form as the most perfectly turned billiard balls. Most of them were black, but some were transparent and crystal-like, others opaque and white, many yellow and brown, and variegated like polished agates or carnelian of different tints; others looked like rusty cannon-balls, and some of these had an aperture in them like a bomb-shell, while others were perforated in all directions; and many were less than one-hundredth of an inch in diameter: some of the globules were magnetic. No analysis was made of these globular bodies, but it was conjectured that the transparent ones were silicates of soda or potash, the opaque white ones silicates of soda or potash with lime and alumina, the yellow and brown ones silicates coloured by oxide of iron, the black ones silicates coloured either by carbon or by magnetic oxide of iron; that others were balls of iron coated externally with a silicate, and that the rust-coloured cannon-ball-like ones consisted of sesquioxide of iron

⁶ Proceedings of the Literary and Philosophical Society of Manchester, 1866-7, vi. 143.

resulting from the oxidation of the iron-pyrites in the coal, and of the perforated shells of protosulphide of iron. The dust containing the globular bodies had been exposed for a considerable time to the intensely heated flame from the furnace. Dancer suggests that the globular form might be due to particles having been thrown off in scintillations. I have pleasure in acknowledging my obligation to that well-known optician for specimens of the globules mounted in slides, which are exceedingly interesting objects under the microscope.

PRACTICAL REMARKS ON THE ASHES OF COAL.

In the choice of coal, attention should be directed to the *nature* as well as the *proportion* of the ashes which it may yield. The proportion may be so great as to lessen its value in a very material degree, or even to render it useless as a fuel for many purposes, and it may vary sensibly even in different parts of a single lump of coal. It may be determined by incineration at a red-heat in a platinum or porcelain crucible. The process may be conveniently conducted either over an air-gas flame or in a muffle. Complete analyses of the ashes of various kinds of coal will be given in the sequel. In respect to the *nature* of the ashes, the amount of oxide of iron is a point of chief importance. Iron-pyrites is, as previously stated, present in all coal, and will be represented in the ashes by an equivalent proportion of sesquioxide of iron, provided incineration be perfect; and generally by far the greater portion of the oxide of iron in the ashes is derived from pyrites. The proportion of that oxide may be sufficient to give a red colour to the ashes, or it may not be sufficient to cause sensible coloration; hence the distinction between *red-* and *white-ash* coals. The intensity of the red colour, taken in connection with the amount of ashes in coal, may serve as an indication of the proportion of sulphur existing in the state of pyrites. When a coal contains pyrites in considerable quantity, especially in the state of nodules, it may speedily destroy the fire-bars of a furnace. In one instance in which a highly pyritic coal was employed in a reverberatory furnace I observed ferruginous masses depending like stalactites from the lower surface of the bars, which were rapidly corroded in consequence.

When the ashes sinter together or melt, they form a more or less vitrified mass termed *clinker*, which may accumulate upon the bars so as greatly to impede the passage of air between them, and, as a consequence, lower the temperature of the furnace. Moreover, when the bars are covered with a firmly adherent bed of clinker, and are no longer cooled by a continuous current of cold air, they may soon become heated and destroyed by oxidation. Now the presence of much oxide of iron in the ashes may, in a certain degree, increase their fusibility, and so tend to induce the evil arising from the formation of an impervious bed of clinker. In this case a greater expenditure of manual labour would be required in removing the clinker, or, as it is termed, in *clinkering* the grate. But sometimes a bed of

clinker is expressly formed, and made to serve an important purpose. Thus in furnaces in South Wales, and some other localities, such a bed is ingeniously used as a substitute for a grate, on which small and inferior coal may be profitably consumed. The bed is allowed to become 12 or 20 inches thick, and requires to be supported only by a few bars, which, being far removed from the fuel, remain comparatively cool. It is kept broken up, so that a sufficient quantity of air may traverse it; and, in proportion as it accumulates above, it is cut away underneath by means of a crowbar with a cutting edge, and a heavy hammer. This operation is termed *breaking the grate*. However, as a rule, the less a coal clinkers the better for most purposes, and for none more so than for boiler-furnaces. Irrespective of the formation of clinker, a certain amount of inorganic matter in coal is sometimes beneficial in preventing its too rapid combustion in the furnace. On this account a kind of coal call *brasils*, which occurs in the middle of the Ten-yard coal in South Staffordshire, is preferred for reverberatory furnaces by some smelters in Birmingham.

GASES OCCLUDED IN COAL.¹

On listening in some collieries, with the ear near a freshly-cut surface of coal, a peculiar singing sound may be distinctly heard, which is caused by the escape of occluded gas; and some kinds of coal continue to evolve gas for a considerable time after they have been raised from the pit and freely exposed to the air. The explosions which occur occasionally in the holds of ships laden with coal are due to accidental ignition of a mixture of atmospheric air with carburetted hydrogen gas evolved from the coal.² According to

¹ I have ventured to apply the term *occluded* to the gas present in coal.

² I have collected the records of such explosions which have happened in recent years, and I present the following selection by way of examples:—"Nov. 22, 1868, the gas from coal exploded in the Norwegian ship *Nordstein*, laden with coal from Newport for the Havannah, when she was about 30 miles west of Scilly. One man was killed, and another fearfully burnt about the face and hands. The men could not launch the boat, but scrambled into it, and it floated as the ship foundered. They were picked up by a vessel from Liverpool and taken to Dover."—*The Times*, Nov. 27, 1868. "July 27, 1866, the screw steamship *Alford*, of London, 638 tons, laden with coal and cask staves, and on her way from Cardiff to Charente, put in at Plymouth. When off the Land's End, at 4 A.M., the mast-head light was brought down, and shortly afterwards an explosion of coal-gas occurred forward. The upper part of the head of the boatswain was blown off,

and another seaman had several ribs broken, but the rest of the crew were forward and escaped injury. Several feet of the deck were blown up, and the iron combings of the hatchway of the fore-hold were torn to pieces."—*The Times*, July 28, 1866. "Nov. 20, 1871, at night an explosion occurred on board the Cunard screw steamer *Samaria*, anchored in the Sloyne at Liverpool. Previous to leaving for New York explosive gas accumulated in the coal-bunkers, and seven seamen were removed to the hospital seriously burnt."—*The Times*, Nov. 21, 1871. "The official report of the Enquiry instituted by the Board of Trade into the loss of the iron screw steamer *Zeno* has just been issued. The Enquiry was held before Mr. Wrangham, stipendiary police magistrate, assisted by Captain White, R.N., and Mr. W. Darley, naval architect, nautical assessors. The *Zeno* was a screw steamer, built of iron, and was the property of Messrs. Wilson, Sons, and Co., of Hull. Her estimated value was £38,000. She was insured for £11,000.

Marsilly, that gas is spontaneously evolved from newly-won coal, even under a pressure five times as great as that of the atmosphere; but after having been exposed to the air during six months, or probably less, coal yields no gas, not even when heated to 300° C. This statement, however, has not been confirmed by recent investigations, especially those of Von Meyer, as will be shown in the sequel. Marsilly has obtained the following experimental results relating to the subject under consideration. Coal loses less in weight by drying *in vacuo* at the ordinary temperature than by heating to 100° C. At 50° C. gas begins to escape from coal, but not very sensibly until the temperature reaches 100° C. and upwards. The evolution of gas continues to increase up to 330° C., when, probably, decomposition of the coal, properly so called, commences. The quantity of gas evolved varies from 1 to 2 litres (61 to 122 cubic inches) per kilogramme (2½ lbs. avoirdupois, nearly) of coal; and there is also distilled a liquid product, having the odour of benzine, and varying in weight from 10 to 15 grammes (154 to 231 grains) per kilogramme. The loss of weight which coal suffers between 50° C. and 330° C., owing

She was built in 1871 by Messrs. Earle and Co.'s Shipbuilding Company, Hull, and classed 18 years Liverpool. She was brig-rigged, was manned with 29 hands all told, and was well found in every respect. On May 7 she was loaded at Cardiff with 1500 tons of fresh wrought Cardiff hard brittle coal from the pits. On the 11th of May she got under way, and two days afterwards one of the sailors took a naked light into the fore peak, when an explosion followed, which so seriously injured the steamer that the crew took to the boats, and in about 50 minutes the Zeno went down head foremost in the Bay of Biscay. The Court found that no blame whatever attached to the owners, and they had the utmost confidence in the substantial construction of the Zeno and of her general efficiency. They exonerated Edward Owen, the master, and returned him his certificate, the usual notice on shipment of dangerous Cardiff coal not having been given to him. With regard to Joseph Whalley Taylor, the chief mate, they considered he neglected his duty in not informing the captain of the dangerous condition of the coal after having been informed thereof by the agent at Cardiff. His certificate was therefore suspended for three months from the 11th of June. The Court felt bound, however, to point out to the Board of Trade the very dangerous properties of the Cardiff steam hard brittle coal, such as shipped in the Zeno, with the view of stringent instructions being given to prevent vessels going to sea without some efficient ventilation. Various means were suggested, among

which were the following:—A comprehensive system of ventilation from the upper deck by pipes, cowls, &c. Had the Zeno been fitted with a cowl and ventilating pipe to the fore peak, this accident would not have occurred. The use of iron masts, uptakes to funnels of steamers, bitts, &c. By dividing the coal fore and aft by planks placed Venetian way, with a space between them, against the pillars of the hold. Also the funnel of the galley fire being utilized by means of pipes leading to it from the various parts of the hold. That each hatchway be arranged so as to admit of cowls being fitted to allow of ventilation when the weather prevents the hatches being taken off. It may be remarked from the evidence that it is more important with Cardiff hard brittle coal to have ventilation than to keep out water."—*The Times*, Aug. 30, 1873. "Last evening, about five o'clock, a fatal gas explosion occurred on board the Swedish brigantine Johanna Mathilda, Captain Niels Olsen, lying off Mill Dam, on the south side of Shields Harbour. The vessel was laden with gas-coal, and was ready to sail for Riga. The hatches were battened down, and the crew were engaged cleaning decks for sea, when the after part of the hold suddenly exploded, shattering the decks and destroying the cabin and cook-house. Olaf Olsen, the mate, was blown into the air and killed instantly. Three others of the crew—Enritz Anderson, Carl Jorensen, and Peter Sjøstrem—were also severely injured."—*The Times*, April 15, 1874.

to the separation both of gas, carburetted oils (*huiles carbonées*), and water, ranges from 1 to 2 per cent.; and as coal after a certain period of exposure to the air ceases to evolve gas, even at 300° C., Marsilly is disposed to infer that the volatile matter which is liberated from fresh coal below 330° C., and which amounts to from 1 to 2 per cent. of the weight of the coal, is the same both in kind and quantity as that disengaged from the same coal by exposure to the air at the ordinary temperature, an inference that cannot be accepted in the absence of analytical evidence. Marsilly asserts that carburetted hydrogen (*hydrogènes carbonés*) is always and almost exclusively evolved from the coal of pits subject to fire-damp, and that the gas evolved from the coal of pits free from fire-damp consists chiefly of nitrogen.³

Dr. Ernst von Meyer has investigated in Kolbe's laboratory the nature of the gas evolved from the coal of various localities, when pieces of it of the size of nuts are kept heated in water during many hours at 100° C., but not so that there is actual boiling.⁴ Coal from Zwickau, which had lain during several months in a cellar in contact with the air, was submitted to experiment, and the composition of two portions of the collected gas was found to be as follows:—

COMPOSITION, PER CENT., BY VOLUME OF GAS EVOLVED FROM ZWICKAU COAL
AT 100° C.

| | I. | II. |
|---|-------------|-------------|
| Carbonic acid | 16·9 | 22·4 |
| Marsh-gas | 20·4 | 22·3 |
| Nitrogen..... | 53·3 | 48·0 |
| Oxygen..... | 1·7 | 4·1 |
| Heavy carburetted hydrogen absorbable by fuming sulphuric acid | 7·7 | 3·2 |
| | <hr/> 100·0 | <hr/> 100·0 |

These results are unsatisfactory, because coal fresh from the pit was not the subject of experiment, and oxidation with the production of carbonic acid takes place, in a certain degree, as will be hereafter shown, when coal is left in contact with atmospheric air; and, even if coal fresh from the pit had been operated upon, it would be necessary to demonstrate that the gas evolved at 100° C. is the same as that which would escape *in vacuo* at the ordinary temperature.

Von Meyer has pursued this interesting subject, and investigated the nature of the gas disengaged from various Saxon, Westphalian, and British coals; and his results will be found recorded in the following tables:—

³ Ann. des Mines, s. 5, 1857, xii. 347 *et seq.* A Report upon Marsilly's researches was presented to the Académie des Sciences, and published in the Comptes rendus for 1858, xvi. 882 *et seq.*; but it should be remarked that some of the statements in the Report are not to be found in Marsilly's original paper. It is

not clear whether the coal experimented upon by Marsilly had been previously desiccated; if not, it probably evolved 1 per cent. or more of hygroscopic water at a temperature of about 100° C.

⁴ Erdmann's Journal für praktische Chemie, 1871, cxii. 42; 1872, cxiii. 144 and 407.

| | | | | | | | | | |
|-------|--|----------------|-------|-------|-------|-------|-------|------|------|
| IV. | Do. 656 metres deep. Had been exposed during 1½ year to the ventilation air-current of the pit. It showed traces of weathering, but internally its fracture was bright | 18.6 | 2.25 | 0.70 | 23.89 | 73.16 | .. | .. | .. |
| V. | "Lehekohle" (name of seam). 560 metres deep. Fresh winning. Hard, irregularly schistose, with bright fracture..... | 52.8 | 0.60 | trace | 48.00 | 51.40 | .. | .. | .. |
| | a. Do. 690 metres deep. Had been exposed during five years to the ventilation air-current of the pit. Appeared outwardly weathered, brittle, not particularly schistose..... | 13.6 | 7.62 | 2.44 | 50.75 | 15.88 | 22.35 | 0.96 | .. |
| VII. | b. Do. do. Gas collected a week after a. had been collected..... | .. | 10.10 | 2.60. | 50.53 | 10.18 | 23.32 | 1.45 | 1.82 |
| | a. Do. do. Gas collected two months after b. had been collected | .. | 11.18 | 2.82 | 67.99 | .. | 18.36 | 1.65 | .. |
| | From the "PLAVEN'SCHE FORMATION." "Harter Schiefer" (local name). Evolved gas copiously. This and the two following were freshly gotten, and from the same pit, named "Burgk." "Weicher Schiefer" (local name). Lively evolution of gas..... | not determined | 48.7 | 1.8 | 49.5 | .. | .. | .. | .. |
| VIII. | "Maschinenschiefer" (local name). Evolved gas most copiously of the three | Do. | 38.2 | 1.2 | 60.6 | .. | .. | .. | .. |
| IX. | All these coals (VII, VIII, IX.) were rich in disseminated iron-pyrites; they were greyish-black, and lacked the lustre and blackness of true Carboniferous coals. | Do. | 54.9 | 1.2 | 43.9 | .. | .. | .. | .. |
| | WESTPHALIA. X. From the "Zollverein" pit, near Essen | 22.5 | 7.50 | 2.59 | 89.91 | .. | .. | .. | .. |
| XI. | From the "Consolidation" pit, do. | 17.4 | 2.56 | 4.11 | 58.48 | 24.85 | .. | .. | .. |
| | Both of these coals (X, XI.) were true "fat coals," much valued for gas-making. a. "Sonnenschein" seam, near Bochum. Distinctly laminated, with here and there iron-pyrites. Freshly gotten | 50.6 | 4.87 | 2.66 | 75.82 | 16.65 | .. | .. | .. |
| XII. | b. Do. do. Had been exposed during a year to the ventilation air-current of the pit..... | 43.2 | 11.12 | 2.88 | 78.60 | 7.40 | .. | .. | .. |

* II. 4, and 5 are reported in the Journal für praktische Chemie, 1873, cxlii, 416. H. Meyer conjectures that butylene may have been present.

and g

TABLE SHOWING THE AMOUNT AND COMPOSITION, PER CENT., BY VOLUME OF THE GAS EVOLVED FROM CERTAIN SAXON AND WESTPHALIAN COALS AT 20° C.—continued.

| LOCALITY. | Number of Cubic Centimetres of Gas Yielded by 100 Grammes of Coal at 20° C. | Composition of the Gas. | | | | | |
|-----------|--|-------------------------|---------|-----------|--------------|--|-------------------------------------|
| | | Carbonic Acid. | Oxygen. | Nitrogen. | Methane-gas. | Hydride of Ethyl, C ₂ H ₆ [C ₂ H ₄] | Gases absorbable by Sulphuric Acid. |
| XIII. | a. "Dickebank" seam, near Borlum. Very like No. XII. a. Freshly gotten | 2.18 | 2.12 | 70.51 | 25.19 | .. | .. |
| | | 15.84 | 3.06 | 74.53 | 6.57 | .. | .. |
| XIV. | b. Do. do. Had been exposed during a year to the ventilation air-current of the pit | 5.82 | 1.99 | 60.62 | 31.57 | .. | .. |
| | | 7.68 | 2.24 | 86.77 | 8.31 | .. | .. |
| XV. | a. "President" seam, do. Not distinctly schistose, easily friable. Freshly gotten | 1.30 | 1.60 | 68.85 | 30.25 | .. | .. |
| | | 4.35 | 3.35 | 81.18 | 11.12 | .. | .. |
| XVI. | b. Do. do. Had been exposed during a year to the ventilation air-current of the pit | 2.02 | 0.90 | 86.43 | 10.65 | .. | .. |
| | | 2.15 | 3.14 | 91.28 | 3.43 | .. | .. |
| XVII. | a. "Leonhard" seam, do. Distinctly schistose, and contains iron-pyrites. Freshly gotten..... | 3.72 | 0.89 | 90.19 | 5.70 | .. | .. |
| | | 8.49 | 3.57 | 87.94 | trace | .. | .. |

WESTPHALIA—continued.

a. "Dickebank" seam, near Borlum. Very like No. XII. a. Freshly gotten

b. Do. do. Had been exposed during a year to the ventilation air-current of the pit

a. "President" seam, do. Not distinctly schistose, easily friable. Freshly gotten

b. Do. do. Had been exposed during a year to the ventilation air-current of the pit

a. "Wilhelm" seam, do. Not distinctly schistose, here and there fibrous, with lustre of graphite. Freshly gotten

b. Do. do. Had been exposed during a year to the ventilation air-current of the pit

a. "Franziaka" seam, do. Distinctly schistose, rich in iron-pyrites. Freshly gotten

b. Do. do. Had been exposed during a year to the ventilation air-current of the pit

a. "Leonhard" seam, do. Distinctly schistose, and contains iron-pyrites. Freshly gotten.....

b. Do. do. Had been exposed during a year to the ventilation air-current of the pit

All the specimens from XII. to XVII. inclusive were from the "Constantine the Great" Colliery; and in this table they are arranged in the order of their geological age, beginning with the oldest, No. XII.

Von Meyer considers it certain that II. *g.* contained, in addition to hydride of ethyle, hydride of propyle or a still higher member of the series C^mH^{m+2} [C^mH^{m+2}]; and he thinks it probable that the effect of long-continued heating (as in II. *e.* and *g.*) is not to produce any new compound, but only to expel gases pre-existing in the coal. He suggests that it would be interesting to investigate the nature of the gas occluded in the coal of the Saarbrück basin, because G. Bischof stated that he had discovered olefiant-gas in the pit-gases of that district; and if this statement should be confirmed by modern chemists, skilled in the practice of the accurate analytical methods of the present day, it might reasonably be anticipated that the same gas would be detected in the gases occluded in the coal of that district.⁵

TABLE SHOWING THE AMOUNT AND COMPOSITION, PER CENT., BY VOLUME OF THE GAS INVOLVED FROM CERTAIN COALS OF NORTHUMBERLAND AND DURHAM (? AT 20° C.).⁶

| Locality of the Coal, Northumberland and Durham. | Number of Cubic Centimetres of Gas yielded by 100 Grammes of Coal. | Composition of the Gas. | | | | Character of the Coal. |
|--|--|-------------------------|---------|-----------|-------------|--|
| | | Carbonic Acid. | Oxygen. | Nitrogen. | Methan-gas. | |
| I. { From the Low Main Seam, Bewicke Main Colliery } | 25.2 | 5.55 | 2.28 | 85.65 | 6.52 | { Weathered externally. |
| II. { From the Mandlin Seam, Bewicke Main Colliery | 30.7 | 8.54 | 2.95 | 61.97 | 26.54 | { Very hard, bright, with conchoidal fracture. |
| III. { From the Main Coal Seam, Urpeth Colliery | 27.6 | 20.86 | 4.83 | 74.31 | .. | { Bright fracture. |
| IV. { From the 5-Quarters Seam, Urpeth Colliery, about 30 fathoms from the surface .. } | 24.4 | 16.51 | 5.65 | 77.84 | trace | { Bright fracture. |
| V. { From the 5-Quarters Seam, Wingate Grange Colliery, 74 fathoms from the surface .. } | 91.2 | 0.34 | trace | 13.96 | 85.80 | { Here and there fibrous in structure. |
| VI. { From the Low Main Seam, Wingate Grange Colliery, 106 fathoms from the surface .. } | 238.0 | 1.15 | 0.19 | 14.62 | 84.04 | |
| VII. { From the Harvey Seam, Wingate Grange Colliery, 148 fathoms from the surface .. } | 211.2 | 0.23 | 0.55 | 9.61 | 89.61 | { Very hard, containing iron-pyrites, with bright conchoidal fracture. |
| VIII. { From the Upper or Harvey Seam, Woodhouse Close Colliery, 25 fathoms from the surface | 84.0 | 5.31 | 0.63 | 44.06 | 50.01 | |

The gas evolved from most of the coals experimented upon contained the same constituents as that generally found in coal-pits, though not in the same relative proportions. The question of the source of the nitrogen in pit-gas and in the gas occluded in coal is one of much interest. Bischof supposed that it is derived, not from the atmosphere, but from the organic matter which by slow decomposition has been converted into coal. Von Meyer, however, observes that, as free nitrogen has never been certainly proved to result from

⁵ Bischof published two interesting papers on the subject in 1841 in the *Edinburgh New Phil. Journ.* xxix. 309, and xxx. 127.

⁶ Ueber die in einigen englischen Steinkohlen eingeschlossene Gase, von Dr. Ernst von Meyer, *Erdmann's Journal für praktische Chemie*, 1872, cxlii. 407.

any natural process of decay, it seems more probable that it was derived from the atmosphere. In support of the atmospheric origin of the nitrogen, Von Meyer remarks that in most of the gases he analysed the proportion of carbonic acid was considerably less than it would have been if all the oxygen, corresponding to the nitrogen present (i.e. supposing the oxygen and nitrogen in question to be of atmospheric origin, and to have been absorbed in the proportions in which they exist in the atmosphere), had been consumed in the formation of that acid. And as according to Richters, whose investigations concerning the weathering of coal will be given in the sequel, more oxygen is absorbed from the atmosphere, in weathering, than suffices to oxidize that portion of the carbon which is evolved in the state of carbonic acid, Von Meyer conceives that the proportion of oxygen absorbed may have corresponded to that of the nitrogen present in the gases. An exception occurred in the case of the gas from the Burgk coal (VII., VIII., and IX. of the first table), which contained more carbonic acid than corresponded to the nitrogen present. But this coal was rich in iron-pyrites: hence Von Meyer infers that oxidation may have been more energetic, and, as a consequence, more oxygen may have been absorbed and carbonic acid produced than in the case of the other coals.⁷

Von Meyer observes that, although he did not examine weathered coal, strictly so called, for weathering action is much more energetic in coal freely exposed to the atmosphere than in such as is merely exposed to the ventilation current of a coal-pit [?—J. P.], yet in all his experiments he found more gas in fresh than in old-gotten coal; and the difference was most marked in the coals of Zwickau. In the old-gotten Westphalian coals the proportion of marsh-gas was less than in the fresh coals, and the proportion of carbonic acid greater, though not in a degree corresponding to the decrease in the former gas. In the old-gotten Zwickau coal (IV. of the first table) there was an increase in the proportion of marsh-gas, but it is only relative, as the quantity of occluded gas is smaller than in the fresh coal (III. of the same table) belonging to the same seam. The conjecture that the youngest coal ought to contain most gas, was not confirmed by Von Meyer's results, and no variation in the proportion of occluded gas, corresponding to the geological age of the seams, was discovered. There was, however, great variation in the composition of the occluded gas in the coal from different beds of the same series, as will be perceived by inspecting the column headed Hydride of Ethyle in the first table. This hydro-carbon was almost always accompanied by gas absorbable by sulphuric acid; and if this gas should prove to be butylene, which has been found in petroleum, the conclusion can hardly be resisted that butylene is the product of the dry distillation of coal. In one instance (VI. c. of the first table), after an exposure of only 2 or 3 months, the whole of the marsh-gas originally

⁷ Compare, however, Richters' results regarding the spontaneous ignition of coal given on p. 299 *infra*.

present in the coal had disappeared, while the greater part of the hydride of ethyle remained.

Although gas in sensible quantity may be occluded in coal at ordinary atmospheric pressure, yet occasionally it is condensed under great pressure, and escapes at a high velocity when a coal-seam or the contiguous measures are first cut into, producing what colliers term "blowers." In some cases of this kind gas in enormous quantity has been disengaged in the course of a few minutes, and in others has continued to flow without intermission during several years afterwards.⁸ Jars states that at Workington, when he visited it in 1765, fire-damp was conveyed from the old workings of a coal-pit to the surface, by an iron pipe. When the gas was ignited at the mouth of the pipe, which did not exceed $1\frac{1}{2}$ inch in diameter, it "burned perpetually," producing a bluish and feebly luminous flame, like that from spirit of wine, about a foot in height. A short time previously, at Whitehaven, fire-damp had been conducted in like manner from a coal-pit to the surface; and "the manager proposed at that time to the magistrates of the town of Whitehaven to carry separate pipes from the pit into each street of the town, and by that means light all the streets during the night."⁹ This is a very early, if not the first, published proposal to apply gas to the lighting of a town. As an instance of the existence of gas under considerable pressure in the Coal-measures, the following may be given, which occurred in Scotland in 1866. In the process of boring for ironstone, when a depth of 420 feet had been reached, there escaped from the bore-hole, of $2\frac{1}{2}$ inches in diameter, a copious current of gas, which became accidentally ignited, and produced a loud-roaring flame from 20 to 30 feet in height. When the fire broke out, the workmen tried to stop up the bore-hole with stout iron rods, using them as rammers, but so strong was the rush of gas that three or four sturdy men were knocked aside. The flame died out a day or two afterwards.¹

WEATHERING OF COAL.

By the word *weathering* is meant the change which coal undergoes by exposure to the air. Some writers in their definition of this word include the change which coal may also spontaneously undergo when atmospheric air is excluded, and which is regarded as the result of a natural tendency to decay supposed to be inherent in coal. But any alteration in coal caused by such a process of decay would probably be inappreciable during the life even of a Methuselah, and may certainly be disregarded by men of this generation.

Weathering is due to the absorption of atmospheric oxygen, of which one portion combines with part of the carbon and part of the

⁸ Instances of this kind have been often recorded, and some will be found in the volume containing the Official Reports of the Coal Inspectors for 1855, p. 23.

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⁹ Jars' *Voyages métallurgiques*, 1774, i. 247.

¹ *The Engineer*, Aug. 24, 1866, quoted from *The Scotsman* newspaper.

hydrogen of the coal, forming carbonic acid and water respectively; while another portion enters into an unknown state of combination with the organic substance of the coal, and the remainder is consumed in oxidizing the iron-pyrites which invariably exists in coal. The calorific power of the coal, and, consequently, its practical value, are thereby diminished; and when iron-pyrites is present in considerable quantity, disintegration may take place to such an extent as to render coal comparatively worthless after long exposure to the atmosphere. Elevation of temperature accelerates and promotes deterioration in the first respect, but moisture does not; whereas in the last respect, or that of disintegration, caused by the oxidation of iron-pyrites, chemical action is favoured by moisture, and in a greater degree by moisture combined with elevation of temperature. Weathering also destroys the caking quality of some kinds of coal.

The weathering of coal has been made the subject of investigation on a large scale by several observers, whose results are in some respects discordant. It would appear from the experiments of Richters and Reder that when there is no rise in the temperature of coal piled in heaps and left exposed to the air during 9 or 12 months, it undergoes no sensible change in any respect; and that, on the other hand, when the coal becomes heated, it suffers precisely the same kind of change as was found by Richters to be effected in coal by heating it in contact with atmospheric air to a comparatively low temperature (as stated at p. 293 *infra*), namely, loss of carbon and hydrogen by oxidation, and increase in the absolute weight of the coal owing to the fixation of oxygen. Grundmann states that in some of his experiments on weathering, the ash was more than doubled in relative proportion after the coal had been exposed to the atmosphere only from the beginning of August to the end of December 1861, in which case not less than half of the organic part of the coal must have disappeared! This conclusion must be erroneous; and it is suggested that the inorganic or ash-yielding matter of the coal may not have been equally distributed through the coal, and that, therefore, the samples of coal analysed before and after exposure to the air may have contained different proportions of such matter.

Fleck has investigated the nature of the change in weathering, and although his results are in great measure free from the source of error suggested as possible in the case of Grundmann's observations, yet they are sufficiently anomalous to justify a suspicion of fallacy. In 1856 a large quantity of each of six kinds of Saxon coal was reduced to powder, and a portion of each analysed. The remainder of the lumps of coal, from which the powders had been derived, were kept until 1865 in a case containing the chemico-technological collection at the Polytechnic Institution in Dresden, and analysed after the lapse of the comparatively long period of 9 years. The results are recorded in the following table: ²—

² Die Steinkohlen Deutschlands und anderer Länder Europas, etc., by Geinitz, Fleck, and Hartig, 1865, ii. 221.

FLICK'S TABLE SHOWING THE ACTION OF WEATHERING ON THE CHEMICAL COMPOSITION OF COAL.

| Kinds of Coal. All from the Carboniferous System. | Year in which the Analysis was made. | Percentage Composition of the Coal dried at 105° C. | | | | Percentage Composition exclusive of Ash. | | | | Hydrogen per 1000 parts of Carbon. | |
|---|---|---|-----------------|----------------------------------|------------------|--|-----------------|----------------------------------|----------------------------|---------------------------------------|---------------------|
| | | Percentage Composition of the Coal dried at 105° C. | | | Ash. | Percentage Composition exclusive of Ash. | | | Oxygen and Nitrogen. | Disposable. | Non- disposable. |
| | | 1. Carbon. | 2. Hydrogen. | 3. Oxygen and Nitrogen. | | 4. Carbon. | 5. Hydrogen. | 6. Oxygen and Nitrogen. | | | |
| I. { Hard, shaly coal, from the Oppelt pit in Zaukeroda ... } | 1856 1865 | 67.173 47.219 | 4.630 2.814 | 11.458 14.979 | 16.739 34.988 | 80.768 72.632 | 5.567 4.398 | 12.965 23.970 | 48.856 21.024 | 20.069 39.528 | 9. |
| II. { Coal from the third seam of the Oppelt pit. [Is not this as much shale as coal?] ... } | 1856 1865 | 26.544 32.779 | 1.904 1.756 | 7.320 11.132 | 64.252 53.833 | 74.230 70.241 | 5.325 3.764 | 20.445 25.995 | 37.303 7.331 | 34.434 46.255 | 9. |
| III. { Coal from the second seam of a colliery (des Gühne'schen Werkes) in Niederwüsch- nitz | 1856 1865 | 81.573 80.300 | 4.477 4.650 | 9.473 13.569 | 4.477 1.481 | 85.396 81.510 | 4.687 4.720 | 9.917 18.770 | 40.365 33.793 | 14.520 21.114 | 9. |
| IV. { Soft, shaly coal from the Gückelsberg pit..... } | 1856 1865 | 87.825 86.217 | 2.663 2.653 | 4.670 5.160 | 4.843 5.970 | 92.295 91.434 | 2.798 2.822 | 4.907 5.744 | 23.669 23.010 | 6.646 7.853 | 9. |
| V. { Coal (Peckholze) from Hel- big & Co.'s pit in Ober- holandorf..... } | 1856 1865 | 80.963 79.472 | 5.518 4.645 | 12.081 19.728 | 1.498 2.155 | 82.113 75.972 | 5.602 4.747 | 12.285 19.281 | 49.518 30.761 | 18.705 31.722 | 9. |
| VI. { Coal from the upper seam of the Segen Gottes pit in Zwickau | 1856 1865 | 75.747 76.963 | 4.881 4.166 | 15.570 16.555 | 3.802 2.916 | 78.740 78.658 | 5.074 4.272 | 16.186 17.070 | 33.748 27.168 | 25.692 27.130 | 9. |

Now, if portions of the *same samples* of the coals, referred to in the preceding table, had been analysed in 1856 and 1865, it would follow that in some instances a large proportion of the organic substance of the coal must have disappeared; for the inorganic matter constituting the ashes could not have increased under the conditions in which the coal had been preserved. But loss of organic matter to the extent indicated in some cases is incredible; and the experiments were, doubtless, vitiated by the fact that the samples analysed in 1865 did not originally contain the same proportion of inorganic matter respectively as those analysed in 1856. No conclusion, therefore, can be drawn from the numbers in column 4. While the inorganic matter may be unequally distributed through a lump of coal, there is reason for believing that generally the composition of the organic matter in that lump is not subject to similar variation in chemical composition; and if this be so, then satisfactory conclusions may be drawn from the numbers in columns 5, 6, 7, 8, and 9. Now, these numbers show that in every instance the relative proportions of the carbon and the disposable hydrogen had sensibly decreased, and that the relative proportion of the non-disposable hydrogen had sensibly increased, after the lapse of 9 years; and, consequently, that the coals had suffered corresponding deterioration in calorific value.

E. Richters, of the Mining School at Waldenburg,³ has recently investigated the action which takes place during the weathering of coal; and as it is of much interest in a scientific, and of much importance in a practical, point of view, I have extracted the following detailed information from his published reports.

As previously stated, when coal is left at ordinary temperatures in contact with oxygen, either pure, or mixed with nitrogen as it exists in atmospheric air, it absorbs that gas, of which one portion combines with carbon and hydrogen, forming carbonic acid and water respectively, while another portion of it enters into an unknown state of combination with the coal and proportionately increases its weight. In support of this proposition the following experimental evidence, obtained by Richters, is adduced.

Two varieties of lignite were operated upon, one fibrous and wood-like in structure (I.), and the other earthy (II.): their percentage composition was as follows:—

| | I. | | II. |
|---------------------------|---------------|-------|---------------|
| Carbon | 55.97 | ..... | 53.64 |
| Hydrogen | 5.65 | ..... | 5.32 |
| Oxygen and nitrogen | 36.02 | ..... | 32.84 |
| Ash | 2.36 | ..... | 8.20 |
| | <u>100.00</u> | ..... | <u>100.00</u> |

Both are said to have been free from iron-pyrites.

³ See his articles in Dingler's Polytechnisches Journal for 1870, cxcv. 315 and 449; and cxvii. 317. An excellent résumé of these papers will be found in Wagner's Jahresbericht for 1870, xvi. 758-778.

I. contained 1.12, and II. 1.22 per cent. of hydrogen in excess of what is required to form water with the oxygen present, i.e. of disposable hydrogen.

The following experiments were made:—

- I. 10 grms., moistened and left in contact with atmospheric air over mercury, absorbed in 6 days 4.3 c. c. (cubic centimetres) of oxygen, and 3.6 c. c. of carbonic acid were produced.
- II. 10 grms., treated in like manner during the same period, absorbed 4 c. c. of oxygen, and 3.11 c. c. of carbonic acid were produced.

Moist lignite, whether freshly-gotten or after having been long exposed to the air, was found to absorb oxygen.

Richters ascertained that 20 grms. of various freshly-gotten coals of the Carboniferous system, when in the state of powder freed from dust by means of a sieve, absorbed from 2 to 9 cubic centimetres of oxygen from moist atmospheric air in the course of 24 hours. Absorption begins very soon, and proceeds with proportionate rapidity. Varrentrapp had previously shown that carbonic acid is formed by passing a current of atmospheric air over coal at ordinary atmospheric temperatures. The change which coal undergoes by exposure to the air is greatest at first; and although, according to Richters, the power possessed by coal of absorbing oxygen becomes continually weaker with time, yet it never entirely ceases. It follows, therefore, that freshly-gotten coal should absorb oxygen more vigorously and more quickly than such as has been long exposed to the air.

The action of oxygen upon coal is much promoted by heat, even at temperatures not exceeding 70° or 80° C.; and evidence of this fact will be found in the table on the next page, in which are recorded the results of Richters' experiments on the subject.

Coal, it will be perceived from that table, was kept heated, dry as well as moist, during a certain period in contact with atmospheric air, and its composition was ascertained before and after that treatment; and in order to demonstrate that increase of temperature did promote oxidation, portions of the same specimens of coal as those operated upon were left exposed to the air at the ordinary temperature during the experiments on heating, and then analysed, by which it was proved that they had undergone no sensible change in composition by such exposure. The products of the oxidation of the organic substance of coal by atmospheric air are carbonic acid and water; and any iron-pyrites which the coal may contain will also be oxidized, especially when the air is moist, with the formation of compounds to be hereafter considered. When coal (*Steinkohle*) in the state of powder is heated to a temperature ranging from 180° C. to 200° C., it at first continues to gain in weight, more oxygen being absorbed than the weight of the carbonic acid and water evolved; but on keeping up the temperature, slight reduction in weight occurs, and after a certain time both the weight and chemical composition of the coal will remain constant. In one experiment upon this point the temperature was maintained during six days consecutively without

TABLE SHOWING THE CHANGES WHICH TAKE PLACE IN COAL, WHEN IT IS HEATED TO FROM 70° TO 80° C., IN CONTACT WITH ATMOSPHERIC AIR, AND WITH MOISTURE.

| Treatment to which the Coal was subjected. | Chemical Composition of the Coal per cent. calculated exclusive of Ash. | | | Ash per cent. in the Coal. | Per 1000 parts by weight of Carbon. | | Calorific Power of Ash-free Substance of the Coal. | Increase per cent. in | | Decrease per cent. in | |
|--|---|-----------|----------------------|----------------------------|-------------------------------------|--------------------------|--|-----------------------|---------|-----------------------|-----------|
| | Carbon. | Hydrogen. | Oxygen and Nitrogen. | | Disposable Hydrogen. | Non-disposable Hydrogen. | | Weight. | Oxygen. | Carbon. | Hydrogen. |
| I. { (a) Before heating | 82.90 | 5.25 | 11.85 | 5.70 | 45.48 | 17.85 | 7922 | — | — | — | — |
| (b) After heating in a water-bath during 14 days from 70° to 80° C. | 81.94 | 5.06 | 13.00 | 5.37 | 41.92 | 19.83 | 7741 | 1.01 | 1.28 | 0.13 | 0.14 |
| (c) After heating during 14 days in a water-bath, but during the day kept constantly moist | 82.02 | 5.09 | 12.89 | 5.59 | 42.42 | 19.63 | 7762 | 0.98 | 0.17 | 0.08 | 0.11 |
| II. { (a) Before heating | 84.44 | 5.07 | 10.49 | 2.90 | 44.52 | 15.49 | 8084 | — | — | — | — |
| (b) After heating, as in No. I. (b) | 83.49 | 4.85 | 11.86 | 2.90 | 40.37 | 17.73 | 7842 | 0.25 | 1.20 | 0.74 | 0.21 |
| (c) After heating moist, as in No. I. (c) | 83.81 | 4.90 | 11.29 | 2.91 | 41.63 | 16.75 | 7893 | 0.14 | 0.82 | 0.52 | 0.16 |
| III. { (a) Before heating | 90.73 | 4.25 | 5.03 | 9.87 | 39.92 | 6.92 | 8508 | — | — | — | — |
| (b) After heating, as in No. I. (b) | 88.80 | 4.07 | 7.13 | 9.31 | 35.82 | 10.02 | 8201 | 0.20 | 2.12 | 1.76 | 0.16 |
| (c) After heating moist, as in No. I. (c) | 89.01 | 3.96 | 7.03 | 9.28 | 34.60 | 9.89 | 8183 | 0.45 | 2.04 | 1.82 | 0.27 |

REMARKS ON THE PRECEDING TABLE.

Nos. I. and II. were caking coals, but No. III. was non-caking (*Sand-kohle*), and did not yield coke, properly so called.

The caking power of No. I. (a) being estimated at 1.4, that of No. I. (b) was 1.1.—(See footnote on the next page.)

The caking power of No. II. (a) being estimated at 2.0, that of No. II. (b) was 1.6.

Nos. I. (b, c), II. (b, c), and III. (b, c), did not sensibly differ from Nos. I. (a), II. (a), and III. (a), respectively, either in the yield of coke or specific gravity.

The calorific value of Nos. I. (b), II. (b), and III. (b), was reduced by about 2.62%, 3.61% and 3% [72.28%, 3% and 3.61%] respectively.

The coals operated upon by Richthers were all from the Carboniferous system in Silesia, and had previously stood for a long time in a loosely covered vessel.

causing any appreciable difference in the weight of the coal. This statement, however, by Richters is hardly compatible with that previously made by him, namely, that the power possessed by coal of absorbing oxygen from the atmosphere at ordinary temperatures decreases, but never entirely ceases. Accepting the latter statement as correct, it would seem that one portion of the carbon of coal is oxidized by contact with atmospheric air at temperatures at which the other and by far the larger portion is not acted upon in a sensible degree. According to Richters, after coal has been heated to the maximum of its oxygen-absorbing power, the relation in weight which will then be found to exist between its hydrogen and oxygen will be the same as in water: thus showing, that that part of the oxygen which is absorbed and combines with the carbon, is evolved again as carbonic acid; and that, therefore, with the disappearance of the disposable hydrogen, the permanent absorption of oxygen should cease.

Richters has endeavoured to ascertain whether there is any relation between the power of coal to absorb oxygen and its power to absorb moisture from the atmosphere, and has made more than a hundred experiments upon this point. Different kinds of coal were dried at 100° C. until their weight became *constant* (?), and were afterwards left in contact with atmospheric air, saturated with moisture at 15° C.; and it was found that they absorbed from 2 to 7.5 per cent. of water, and that this property was in no degree dependent, as is commonly supposed, upon the structure of the coal. Thus, compact bright coals (*Glanzkohlen*) not seldom absorb three times as much water as very loose, soft, and tender schistose coals (*Schieferkohlen*) of an almost lamellar structure. But coal from the same seam over a wide extent absorbs the same proportion of water, or shows only very slight difference in its capacity for absorption. Now, Richters found that the quantity of oxygen absorbed by different coals, under the same conditions, is proportionate to the quantity of water which they absorb. It is regarded as more than probable that

Footnote to the Table on the preceding page.—In estimating the relative caking power of coal, Richters used the following method. One gramme of the finely-pounded and air-dried coal is mixed with a definite weight of silica in the state of ground flints, such as is prepared for potters, and put loosely into a platinum crucible, about 3 centimetres deep and as many wide, which, with its cover adjusted, is heated in the coal-gas flame of a single Bunsen burner, so that its bottom may be about 6 centimetres above the orifice of the jet; and the height of the flame should be about 18 centimetres. Heating is to be continued until flame-producing gases cease to be evolved; and when this is the case, the coke is to be carefully placed with its bottom downwards upon a piece of sheet-iron. A

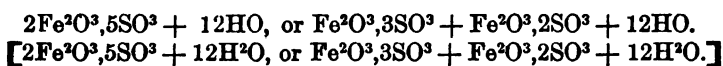
weight of 0.5 kilogr. is then to be cautiously applied to the top of the coke, which will either be crushed or resist the pressure and remain entire. If the former should occur, the experiment is to be repeated with mixtures containing always the same weight of coal and, say, 0.1 grm. less silica each time, until one is found which yields a coke just capable of resisting the weight of 0.5 kilogr.; but if the latter should occur, the same course is to be followed, except that the silica is increased by 0.1 grm. each time. The strongest caking coal of the Waldenburg district required the addition of 2.8 grms. of silica to 1 grm. of coal in order to produce a coke of the necessary quality, and its caking power is, therefore, indicated by the number 2.8.

in the first stages the absorption of oxygen is purely physical, like that of moisture, and that the condensation of the gas precedes its combination with the substance of the coal.

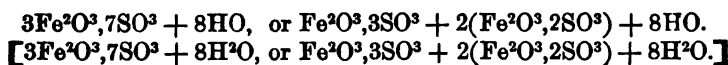
It is interesting to enquire in what degree coal may have the property of absorbing and retaining carbonic acid gas, and what effect that gas when absorbed may have on the subsequent oxidation of the coal in contact with atmospheric air. Answers to these questions are afforded by the following experimental results of Richters, which may be compared with those relating to the absorbent power of wood-charcoal for the same gases, to be mentioned in the sequel:—In a given time and under the same conditions, coal absorbs three times as much carbonic acid as oxygen in volume. Coal, of which the absorbent power for oxygen has been so much reduced by exposure to the atmosphere that 20 grms. of it scarcely take up 1 cubic centimetre in a day, absorbs in the course of a few hours its own volume of carbonic acid. When coal is completely saturated with carbonic acid and then brought into contact with atmospheric air, the volume of the latter is increased by the evolution of carbonic acid, but is afterwards gradually reduced. If in this experiment, which, it need hardly be remarked, should be made in a glass tube closed at one end and inverted over mercury, a little caustic potash or soda be introduced into the tube, the absorption of oxygen will take place pretty rapidly and with correspondingly greater evolution of carbonic acid, which will combine with the alkali. Coal, saturated with carbonic acid, was left during 36 hours under the receiver of an air-pump, exhausted to 2 inches of mercury, when it was found that most, but not the whole, of the carbonic acid had been evolved; and if the coal so treated be saturated with moisture and again put into the tube, absorption of oxygen will occur as vigorously as in the case of freshly-won coal, whether caustic alkali be present or not; the liberation of carbonic acid, which may be quickly detected, indicating that the absorption of oxygen was at first attended with the disengagement of carbonic acid, which, in the absence of a substance capable of combining with that acid, is again taken up by the coal itself. When coal, saturated with carbonic acid, is boiled during half an hour with water, and then dried so as to leave it still saturated with moisture, its original absorbent power for oxygen is completely restored; but when coal, which has lost its power of sensibly absorbing oxygen by long exposure to the atmosphere, is placed under the air-pump, that power is somewhat increased, though not completely restored. From what precedes, it is inferred that the diminution in the absorbent power of coal for oxygen, resulting from long exposure to the atmosphere, is not due to the condensation in it of carbonic acid; and that coal, which has been so exposed, does not, when in contact with air in closed tubes, produce carbonic acid, whereas in the experiments of Varrentrapp that acid is stated to have been always formed when a *current* of atmospheric air was passed over coal.

Richters states that, from his own oft-repeated observations, sunlight lessens or retards the absorption of oxygen by coal.

The oxidation of the organic substance of coal by atmospheric air appears to be generally impeded rather than promoted by the presence of moisture, if we admit that the results recorded in the last table under the head of Decrease per cent. in Carbon and Hydrogen, suffice to justify a conclusion on the subject; for, in every instance, except one relating to hydrogen at the bottom of the last column on the right, less of those elements was oxidized by contact with atmospheric air in the moist than in the dry state. But, on the other hand, the oxidation of iron-pyrites in coal by atmospheric air is favoured by moisture, if, indeed, moisture be not absolutely essential to that action at ordinary temperatures. Richters found that coal poor in sulphur absorbed less oxygen in the moist than in the air-dried state; and, on the contrary, that coal rich in sulphur absorbed less in the air-dried than in the moist state. Sulphate of protoxide of iron or ferrous sulphate, commonly known as green copperas or green vitriol, is the first product of such oxidation, and sulphate of sesquioxide of iron or ferric sulphate is the second. On the face of coal, which has been for some time exposed to the air, as in the gate-road of a colliery, or even in a loosely covered jar, yellow ochre-like spots having a strong inky taste may often be observed, which consist of the last-mentioned kind of salt, a salt certainly very nearly allied to, if it be not identical with, the mineral species designated copiapite or misy, and having, according to Rammelsberg, the formula—



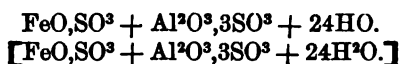
Misy from the Rammelsberg Mine, at Goslar, in the Harz, is stated to have the formula⁴—



The product of the first stage in the atmospheric oxidation of iron-pyrites, that is, sulphate of protoxide of iron, usually makes its appearance in the form of delicate, apparently colourless, fibres, protruding here and there from the surface of the coal; or, if the iron-pyrites be in lumps, these will sometimes be coated with crystals of the sulphate of considerable size and of the characteristic green tint. As the volume of the oxidized products in question greatly exceeds that of the original pyrites, the atmospheric oxidation of the latter in coal will necessarily tend to produce disintegration; and the coal in some localities contains so much of that sulphide as gradually to fall to pieces when exposed to the air during a certain time. The water which flows from coal-mines, particularly from the old workings, is often so richly impregnated with a sulphatic salt of iron as to have a strongly chalybeate taste. Such water will rapidly corrode iron boilers, and will deposit by contact with the atmosphere an insoluble yellow basic sulphate of sesquioxide of iron, while a soluble acid salt

⁴ Rammelsberg's Handbuch der Mineralchemie, 1860, p. 275.

of that oxide will remain in solution. But, according to Richters, the sesquioxide of iron resulting from the oxidation of the protoxide of ferrous sulphate is reduced to protoxide by contact with coal; and he, therefore, suggests that, by such alternate oxidation and reduction, sesquioxide of iron may act as a carrier of oxygen to the organic substance of coal. The oxidation of the iron-pyrites in coal tends to promote the oxidation of the organic substance of coal, because it is attended with a considerable development of heat, and, by swelling, it splits up the coal and so renders the mass more pervious throughout to oxygen. As shale, which it will be remembered consists largely of silicate of alumina, is intermixed with coal, the atmospheric oxidation of iron-pyrites in the latter may give rise to the formation of that beautiful substance which occurs in long, delicate, white, asbestos-like fibres, and is designated feather-alum;⁵ its formula is—



I have a beautiful specimen of it from a colliery near Newcastle-on-Tyne, which has been kept during about thirty years, apparently unchanged, in a corked glass tube, but which decomposes when freely exposed for some time to the atmosphere, and becomes brown owing to the conversion of the protoxide of iron into sesquioxide.

SPONTANEOUS IGNITION OF COAL.

The coal in some collieries is apt to ignite spontaneously when it is allowed to accumulate in the state of dust or fine slack, either in the pit or out of it, or when ribs or pillars of coal are subjected to great crushing weight; and, perhaps, no coal in Great Britain is more liable to such ignition than the Ten-yard or Thick Coal of South Staffordshire. On the contrary, in other collieries the spontaneous ignition of coal is generally unknown. I have had the opportunity of personally inspecting a Thick-Coal pit immediately before the outbreak of fire. The first unequivocal sign of incipient combustion is a peculiar smell, termed "fire-stink" by the colliers, which appeared to me to be precisely similar to that which is produced by distilling coal at the lowest temperature at which decomposition commences. I came to the conclusion that such incipient decomposition had begun, and conceived that it was due to the heat developed by the oxidation of accumulated finely-divided coal, just as in the well-known case of a heap of oiled rags. There was not the slightest odour of sulphuretted hydrogen, and no chemist requires to be informed that that gas is not a product of the atmospheric oxidation of iron-pyrites. In a lecture delivered in 1864, I used these words when speaking about coal: "I am disposed to believe that there is another cause of spontaneous ignition [besides iron-pyrites] similar

⁵ See Rammelsberg's *Handbuch der Mineralchemie*, 1860, p. 288; Thomson's *Outlines of Mineralogy*, 1836, i. 472; and Berthier's notice, *Ann. des Mines*, s. 1, 1820, v. 259.

to that which determines the spontaneous combustion of cotton-waste, namely, the absorption of oxygen by coal reduced to a fine state of division;"⁶ and I had often previously stated the same view in my lectures at the Royal School of Mines. I was led to this opinion mainly by a consideration of the fact that the Ten-yard coal contains only a small proportion of iron-pyrites, usually not more than is equivalent to 0·5 per cent. of sulphur. I had also observed in a part of the old workings of the colliery above referred to, a pretty copious evolution of carbonic acid, which, near the ground, immediately extinguished a lighted candle.

It was reserved for Richters to substitute fact for opinion, and to demonstrate by experiments—which, in my judgment, are conclusive—that, generally, the spontaneous ignition of coal is due to the heat developed by atmospheric oxidation of the organic substance of coal, and not to that resulting from the oxidation of iron-pyrites. He has shown that coal most liable to spontaneous ignition is not that which contains most iron-pyrites; and of this proof is afforded by the following table, in which he has arranged eleven varieties of coal from the Carboniferous system in three classes, according to the degree of their self-inflammability:—

TABLE OF COALS ARRANGED ACCORDING TO DEGREE OF SELF-INFLAMMABILITY.

| Degree of self-inflammability. | Iron-Pyrites %. | Water %. | Character of the Coal. |
|--|---------------------|----------|--|
| Class I. Difficultly self-inflammable... | 1. 1·13 from | 2·54 | Easily friable. |
| | 2. { 1·01 to 3·04 } | 2·75 | Very compact. |
| | 3. 1·51 | 3·90 | Do. |
| Class II. Of medium self-inflammability | 4. 1·20 | 4·50 | Firm, schistose, bright. |
| | 5. 1·08 | 4·55 | Hard, but very brittle. |
| | 6. 1·15 | 4·75 | Moderately tender. |
| | 7. 1·12 | 4·85 | Outwardly very like No. 1. |
| | 8. 1·00 | 9·01 | Moderately tender, schistose. |
| Class III. Readily self-inflammable ... | 9. 0·83 | 5·30 | Moderately soft, schistose. |
| | 10. 1·35 | 4·85 | Do. |
| | 11. 0·84 | 5·52 | Not stated, yielded only 2·5 % of ash. From the same pit as No. 10, but from a different seam, remarkable for its great self-inflammability. |

Atmospheric oxidation of iron-pyrites is always a comparatively slow process, and, consequently, there must be much loss of heat. It is not, however, asserted that iron-pyrites may not, when present in coal in considerable quantity, develop sufficient heat during its oxidation by atmospheric air to set the coal on fire.

From what has been presented concerning the oxidation of coal, indications of value for practical guidance in the working of coal,

⁶ Swiney Lectures on Chemical Geology, Jan. 28, 1864. The Chemical News, July 9, 1864, p. 19.

liable to spontaneous ignition, may be derived. Increase of temperature greatly promotes oxidation, and in proportion to the rapidity of oxidation is the elevation of temperature and consequent risk of combustion. The temperature of the pit should, therefore, be kept as low as possible; but how, it may be asked, is this to be done? By a vigorous current of cool air through the workings; but such a current can only be obtained when the temperature of the external air is much lower than that of the pit. When an outbreak of fire has been apprehended in a particular part of a South Staffordshire Thick-coal colliery, the practice which I have seen was greatly to reduce the current of air in that part; but, except when the temperature of the external air exceeded that of the pit, the result would necessarily be elevation of temperature, more rapid oxidation, and greater probability of ignition. When the supply of air is lessened, there is always amply sufficient left for oxidation. If once combustion begins, an attempt should be made to extinguish the fire by water, notwithstanding such attempts may have frequently failed, and to remove from the pit the coal in which it broke out; and if this be impracticable, the only course to be taken is to dam up that part of the pit and exclude air from it as much as possible.

ACTION OF VARIOUS REAGENTS ON COAL.⁷

Experiments have been made in my laboratory on the action of various reagents, upon lignite, bituminous coal, and anthracite in powder. Heat was not employed, nor were the reagents used in a concentrated state, but the action was allowed to go on during several years: the results are presented in the following table:—

TABLE SHOWING THE ACTION OF VARIOUS REAGENTS UPON LIGNITE, BITUMINOUS COAL, AND ANTHRACITE.

| COAL. | REAGENTS. | | | |
|-----------------------|--|--|---|---|
| | Nitric Acid. | Sulphuric Acid. | Hypochlorite of Soda. | Potash. |
| Lignite | Wholly decomposed; solution light - yellow; residue white. | Wholly decomposed; solution pale orange-red; residue white. | Much acted on; solution deep-red, and thick; residue dark-coloured. | Much acted on; solution very deep red, and thick; residue dark-coloured. |
| Bituminous coal | Much acted on; solution light greenish - yellow; residue dark-brown. | Much acted on; solution of the colour of a light port wine; residue dark coloured. | Less acted on; solution brownish-yellow; residue nearly black. | Also less acted on; solution light yellowish-green; residue nearly black. |
| Anthracite | Apparently unacted on; the acid remained colourless, and the coal black. | Little acted on; solution light-red; residue dark-coloured. | Little acted on; solution light-yellow; residue nearly black. | Very little acted on; solution tinged with yellow; residue nearly black. |

⁷ See also p. 272 *supra*.

ERRORS IN THE ANALYSIS OF COAL.

When coal contains much inorganic matter, especially iron-pyrites, the usual method of calculating its composition from the data obtained in the process of organic analysis may be erroneous in a sensible degree. The ashes left by incineration are estimated as inorganic matter, and the proportion of *oxygen* is found by subtracting the sum of the carbon, hydrogen, nitrogen, and ashes from the amount of dry coal subjected to analysis. By incineration the iron of the pyrites is converted into sesquioxide, and the sulphur, in a greater or less degree, into sulphuric acid, which may remain in combination with any base in the ashes—such as lime—capable of forming a sulphate not decomposable at a red-heat. Supposing the whole of the sulphuric acid to be thus retained in the ashes, for 1 part by weight of iron-pyrites there would be an increase of 1 part by weight due to oxygen derived from the air during incineration. The whole amount of this error, provided no correction be made, would fall upon the oxygen. It is not asserted that the whole of the sulphur is actually converted into sulphuric acid and retained in the ashes, but that a considerable portion of a stable sulphate may be produced during incineration will appear from analyses of coal and coal-ashes in the sequel. It is certain that the alumina in the ashes must, either wholly or in great measure, exist in combination with silica as clay; but clay holds water in combination which cannot be expelled except at a temperature far more than sufficient to decompose coal. Hence, during the process of organic analysis water may be evolved from the clay present in coal, and so occasion an error of excess in the determination of the hydrogen. This source of error has been pointed out by Regnault.⁸ Carbonate of lime is sometimes present in coal in very appreciable quantity, in which case carbonic acid would be evolved during the analysis, and so an error of excess would be caused in the determination of the carbon. M. de Marsilly has observed that, however pure a piece of coal may be, and however homogeneous it may appear to the eye, its different parts do not yield the same proportion of fixed residue by incineration; and the same is true in respect to the proportion of coke obtained by the calcination of different fragments of the same lump of coal. Hence, in every case, the proportion of ash and coke should be determined by operating upon an average sample taken from the powder of a considerable quantity of the coal.⁹

There is, lastly, another source of error, which may result from the absorption of oxygen during the drying of the powdered coal preparatory to combustion. It will be remembered, that such absorption is attended with the evolution of carbonic acid and water, and with sensible increase in the weight of the coal. (See remarks on this subject, under the head of the Weathering of Coal, p. 289 *supra*.)

⁸ Ann. des Mines, s. 3, 1837, xii. 167.

⁹ Comptes rendus, 1848, xvi. 882.

SELECTION OF COAL.

In the selection of coal for any special metallurgical or other operation, the only sure guide is practical trial on the large scale; however desirable, or even necessary, it may be in some cases to supplement such trial by laboratory experiments. Thus it is important that the coal used in certain metallurgical processes should not contain sulphur, or other deleterious substances, in sensible quantity; and to determine whether it does or not recourse must be had to chemical analysis: it may also be important to ascertain the proportions of water and ash-producing matter in coal, which can only be done in the laboratory: further, the ultimate chemical composition of coal affords information with respect to its calorific power which, though it may not be absolutely correct, is yet sufficiently so for practical purposes. But there are various other points to be considered in the choice of coal; such as, whether it gives a long or short flame; whether it is caking or non-caking; whether it decrepitates when heated and produces so large a quantity of fine particles as injuriously to obstruct the passage of air through the mass during combustion; and lastly, whether it sufficiently resists weathering action to be kept in store without loss.

In connection with this subject, the various articles on the different constituents of coal, as well as the article on the Ashes of Coal, may be usefully referred to (see pp. 272 *et seq.*).

CLASSIFICATION OF THE VARIETIES OF COAL.

Since the interest of the metallurgist in coal is restricted to its use as a heat-producing substance, the classification he requires must be mainly founded on the relative calorific power of different varieties; and since the calorific power of coal may be approximately deduced from its ultimate chemical composition, the metallurgical classification of the varieties of coal adopted in this work, and which has already been given (see p. 182), is based on their ultimate chemical composition. But, as it has been proved by the analysis of a very great number of coals from different parts of the world that varieties exist which might be so arranged as to represent the conversion of coal, nearest to peat in composition, by almost insensible degrees into anthracite, it is impossible to classify the varieties of coal in absolutely distinct and well-defined groups, and this the reader is requested to bear in mind when reading what follows.

FRENCH CLASSIFICATION OF COALS.

The French have proposed a classification of coals from an industrial point of view; thus Gruner divides them into 5 classes (exclusive of lignites), of which he says the characters are clearly defined (*nettement tranchés*), but he admits that the passage from one class to another is gradual. This classification is as follows:—

TABLE OF A FRENCH CLASSIFICATION OF COALS EXCLUSIVE OF LIGNITE.*

| Names of the Five Types or Classes. | Composition, per cent., of the Organic Constituents. | | | Number of parts by weight of Oxygen,* taking the weight of Hydrogen as unity. | Percentage of Coke obtained by distillation (i.e. by heating in a close vessel). | Nature and appearance of the Coke. |
|--|--|------------|------------|---|--|--|
| | Carbon. | Hydrogen. | Oxygen.* | | | |
| Dry coals, burning with a long flame | 75 to 80 | 4.5 to 5.5 | 15 to 19.5 | 3 to 4 | 50 to 60 | Pulverulent, or at the most friable. |
| Fat coals, burning with a long flame; or gas-coals | 80 to 85 | 5 to 5.8 | 10 to 14.2 | 2 to 3 | 60 to 68 | Caked, but very friable. |
| Fat coals, properly so called, or furnace coals | 84 to 89 | 5 to 5.5 | 5.5 to 11 | 1 to 2 | 68 to 74 | Caked, moderately compact. |
| Fat coals, burning with a short flame, or coking coals ... | 88 to 91 | 4.5 to 5.5 | 5.5 to 6.5 | 1 | 74 to 82 | Caked, very compact, but little friable. |
| Lean (<i>maigre</i>) coals, or anthracites | 90 to 93 | 4 to 4.5 | 3 to 5.5 | 1 | 82 to 90 | Fritted, or pulverulent. |

* Including nitrogen, the proportion of which, however, is stated rarely to exceed 1 per cent. of the organic constituents; a statement which may, however, be questioned.

LIGNITE.

Under the general term of lignite it is intended to include those varieties of coal which, in point of chemical composition, form the link between peat in the most advanced stage of chemical change, such, for example, as the so-called pitch-peat, and the group of coals of the Carboniferous system, which I have designated non-caking and rich in oxygen, like some of those of South Staffordshire. But, strictly considered, that designation is equally, indeed more, applicable to lignite, which is generally not only non-caking, but even richer in oxygen than the coals grouped in that class. The word lignite, used by British and American geologists, is synonymous with brown-coal of the Germans. Both words are objectionable; for lignite suggests a wood-like quality and brown a colour, which only some varieties of lignite possess. But if the word lignite be taken to indicate proximity to wood in ultimate composition, there is at least something to be said in its favour.

Zincken, the author of a comprehensive treatise on brown-coals, defines these coals as "the fossil accumulations of the more or less carbonized remains of plants occurring in the Tertiary formation," the same definition as that adopted by Regnault in 1837;¹ whereas,

* Ann. des Mines, s. 7, 1873, iv. 182.

¹ Die Physiographie der Braunkohle, von C. F. Zincken, 1867, p. 5. This is a large-sized 8vo volume, which consists of 818 pages, and contains two plates of vegetable impressions, a map, and numerous woodcuts. It is a vast store of information,

especially concerning localities, modes of occurrence, yield, and quality; and its preparation, I should think, must have required years of research and labour. I know no work on the subject comparable with it.

according to Dana, lignite, which he uses as synonymous with brown-coal, belongs to Secondary as well as more modern deposits.² Hence, it appears that even geologists are not agreed upon a definition of lignite.

Lignite is widely diffused over the earth in both hemispheres, from north to south and from east to west.

PHYSICAL CHARACTERS OF LIGNITE.—Lignite is either compact or earthy, sometimes wood-like in appearance and structure, and sometimes slate-like or schistose; conchoidal or uneven in fracture; cleavable or uncleavable; light-yellow, light-grey,³ brown, brown-black, or black; and dull, shining, or fatty in lustre. Its specific gravity is stated to range generally from 1.2 to 1.4, and will vary with the quantity of earthy matter which it contains.

HYGROSCOPIC WATER IN LIGNITE.—During the last 20 years and upwards, I have examined many lignites from various parts of the world, and have nearly always found them to contain a large proportion of hygroscopic water, even from 15 to 20 per cent. after long exposure to the air. Lignite may be deprived of this water by heating it to 100° C. or somewhat higher; but on subsequently being left freely in contact with the atmosphere, it will absorb from the latter the same quantity of water as it had lost by previous desiccation, in this respect resembling wood. This is a point which should be specially regarded in judging of the quality of a lignite; and no analysis of this kind of fuel should be accepted which does not indicate the proportion of water. The following case came under my own observation not long ago. The purchase of the concession of a lignite deposit in a certain locality in South America was about to be concluded for a very large sum, when I directed attention to the fact, that in the analysis of this lignite there was no mention of hygroscopic water, which I found it to contain in notable proportion, and which greatly reduced its value as fuel. The negotiation was in consequence immediately terminated. When a man buys fuel, he should be careful to ascertain that his money is not expended to a considerable extent in the purchase of water, which, during combustion, must be evaporated, and cause great waste of heat.

ACTION OF HEAT ON LIGNITE.—Lignite is generally non-caking, that is, its powder, when heated to redness in a close vessel, does not yield a coherent coke: varieties of it have been found so rich in resin as to cause it to cake from that cause alone.⁴

SUBSTANCES OCCURRING IN ASSOCIATION WITH LIGNITE.—Iron-pyrites, yellow and cubical, or white and prismatic, is a very frequent, if not constant, companion of lignite, and often in such large proportion as to render it quite unfit for fuel and cause it spontaneously to ignite on exposure to the atmosphere, owing to the heat developed by the rapid oxidation of the pyrites. In some metallurgical processes it is

² Manual of Geology, 1863, p. 68.

³ Zincken, Die Physiographie der Braunkohle, p. 7.

⁴ Idem, p. 175.

essential that fuel should be used which is practically free from iron-pyrites, while in others fuel containing much of that sulphide may be used without disadvantage. Zinc-blende, copper-pyrites, galena, realgar, and orpiment are reported to have been met with in lignite from various localities;⁶ and the fact that Daubrée obtained arsenic from certain lignites has been previously recorded in this volume. Zincken mentions all the minerals which have been found associated with Tertiary lignites, and gives much information of interest respecting them; and from his article on that subject the following additional names have been selected, somewhat capriciously it must be confessed:—Sulphur, gypsum, green vitriol, misy, Epsom salts, websterite, phosphorite, kaolin, clay-iron-ore, brown-iron-ore, hæmatite, retinite, and amber.

BITUMINOUS COAL.

This term is commonly applied to coal which burns with a more or less smoky flame, and which, in ultimate chemical composition, occupies a place between lignite and anthracite. The passage of lignite into bituminous coal is as gradual as that of bituminous coal into anthracite, so that there is no precise line of demarcation between these classes of coal. Hence in the class of bituminous coals many varieties of coal are included which in external characters and ultimate chemical composition differ widely from each other. The application of the term *bituminous* to coal has led to the erroneous notion that such coal contains a substance similar to natural bitumen, which dissolves in solvents like ether; but that is not correct in the case of ordinary bituminous coals. By some writers the term bituminous is used to denote the matter which is *volatilized* when a coal is heated to redness in a close vessel, and in that sense it is synonymous with *volatile* matter, both terms being employed indiscriminately. By other writers it has been used to express the so-called *organic* elements of coal other than carbon, namely, hydrogen, oxygen, and nitrogen. *Flaming* would not be a bad substitute for the word bituminous.

The characters of bituminous coals may be summed up as follow:—They are solid, easily frangible, and opaque except in thin slices; dull, shining, or fatty in lustre; black or brown-black in mass, but brown when in the state of fine powder; some soil the fingers, and others do not; they are variable in hardness; even, conchoidal, or uneven in fracture, frequently breaking into pieces more or less cubical or rhombic; they generally exhibit cleavage, due to bedding or pressure, but never crystalline structure; they consist of carbon, hydrogen, oxygen, nitrogen, and sulphur, and of fixed or inorganic matter, besides water, which is generally present in small proportion only; in open fire-places, or in furnaces of ordinary construction, they burn with a

⁶ Zincken, *Physiographie der Braunkohle*, p. 194 *et seq.* His account of the companions of tertiary lignite (*Begleiter der Braunkohle*) fills 126 pages, and much of it is in small type.

more or less smoky flame; and when heated to redness in a close vessel, they leave a solid, carbonaceous, more or less coherent residue or coke, which contains the fixed inorganic matter or ashes.

CAKING AND NON-CAKING COAL.

When some kinds of bituminous coal are heated to a certain degree, they swell, become pasty and sticky, and emit bubbles of gas, which burn with a bright flame as they escape into the air. When lumps or small particles of such coal are rendered pasty by heat, a more or less coherent mass is formed, or, in technical language, the coal is said to *cake*. Even the fine powder of such coal yields, when heated to redness in a close vessel, a pretty firmly coherent mass of coke; whereas that of a non-caking coal yields by similar treatment either a feebly coherent or powdery coke, in which the form of the particles of the original coal may clearly be seen. If a piece of caking coal in the pasty state be taken out of a fire, it will remain for a short time soft and dough-like, but on cooling will become solid and brittle. In the quality of caking there may be every degree, from slight fritting or sintering to almost complete fusion. Caking does not occur at a temperature below that at which the coal suffers decomposition, and is not, therefore, the result of simple fusion. By heating the powder of a non-caking coal in admixture with a due proportion of that of a caking coal, a firm and resisting coke may be produced, the latter coal serving as a cementing material to the particles of the former; and the *modus operandi* may be aptly illustrated by the following simple experiment:—Let a mixture be made of pitch and the powder of anthracite (which shows not the slightest tendency to cake), and let it be heated to redness in a covered vessel. A coherent coke will thus be formed, the pitch first melting and afterwards being resolved into *volatile products* and a *fixed carbonaceous residue*, which acts the part of a cement, and binds firmly together the particles of anthracite. By using proper proportions of pitch and anthracite powder, a coke may be obtained so hard and solid as to yield a metallic ring when struck.

As the passage of vegetable matter into bituminous coal and of the latter into anthracite is gradual, and as neither the first nor the last of those substances is in the least degree caking, it follows that as coal approximates in composition towards vegetable matter in its original state or towards anthracite, it might be expected gradually to lose the property of caking; and that it does so has been proved by experiments on the large as well as on the small scale.

It is interesting to ascertain whether any connection can be traced between the property of caking and the relative proportions of the elements of coal, *i.e.* the elements constituting the coaly matter properly so called. With that view the following table has been compiled, showing the composition of three classes of coal: *viz.*,—I. non-caking coal, approximating towards anthracite in ultimate composition; II. caking coal; and III. non-caking coal, further removed

from anthracite in composition than class II. The composition of each coal has been calculated with the carbon estimated at 100, in order that differences between the relative proportions of the elements may be seen at a glance. The terms caking and non-caking are here used in a practical sense, and are intended to indicate the presence or absence of the caking property in a well-marked degree.

TABLE SHOWING THE RELATIVE PROPORTIONS OF THE ORGANIC CONSTITUENTS OF CAKING AND NON-CAKING COALS.

| | I. Non-caking, rich in carbon. | | II. Caking. | | | III. Non-caking, rich in oxygen. | | | |
|-----------|--------------------------------------|--------|----------------|--------|--------|-------------------------------------|--------|--------|--------|
| | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. |
| C | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 |
| H | 4·75 | 4·45 | 5·49 | 5·85 | 5·91 | 6·34 | 6·12 | 6·04 | 5·99 |
| O } | 5·28 | 7·36 | 10·86 | 14·52 | 18·07 | 21·15 | 21·23 | 22·55 | 23·42 |
| N } | | | | | | | | | |

The proportion of hydrogen in excess of the amount required to form water with the oxygen, or the disposable hydrogen, in these coals, respectively, is as follows:—

| I. Non-caking, rich in carbon. | | II. Caking. | | | III. Non-caking, rich in oxygen. | | | |
|--------------------------------------|------|----------------|------|------|-------------------------------------|------|------|------|
| 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. |
| 4·09 | 3·53 | 4·13 | 4·04 | 3·65 | 3·70 | 3·47 | 3·22 | 3·06 |

These numbers are erroneous to the extent of the nitrogen, which in the calculation has been included in the oxygen, but the error arising from this cause may be regarded as constant and too small materially to affect any conclusion that may be drawn from the table.

Hence it appears that there is no essential connection between the proportion of disposable hydrogen and the property of caking, for the proportion is nearly identical in Nos. 1 and 3, and in Nos. 6 and 5, which are non-caking and caking, respectively. When the proportion of disposable hydrogen much exceeds the maximum stated in the foregoing table, the caking quality disappears. Thus, a variety of cannel coal,⁶ in which the disposable hydrogen amounts to nearly 10 per 100 of the carbon, yielded when heated in a covered crucible a slightly fritted carbonaceous residue, which could be easily crumbled between the fingers.

But we might be led to infer that the property of caking is connected with the proportion of oxygen, and that when it exceeds in round numbers 7 per cent. of the carbon, and does not exceed 18 per cent. of the carbon, the coal would have the property of caking.

It would, however, appear from the researches of Stein, Professor of Chemistry at the Polytechnic School of Dresden, to whom we are indebted for a monograph on the coals of Saxony,⁷ that in some cases

⁶ The "Curly Cannel," Leeswood Green Colliery, of which an analysis will be found in the table, p. 329 (No. 56b).

⁷ Chemische und chemisch-technische Untersuchung der Steinkohlen Sachsens, by W. Stein, 1857.

caking and non-caking coals may have the same ultimate composition; and in exemplification the following series of analyses has been selected from that work and is presented in a tabular form:—

TABLE SHOWING THAT CAKING AND NON-CAKING COALS MAY HAVE THE SAME ULTIMATE COMPOSITION.

| Number. | Specific Gravity. | Composition, per cent., exclusive of Water only. | | | | | | Coal air-dried, Water per cent. | Composition, per cent., exclusive of Sulphur, Ash, and Water. | | | | Coke per cent., exclusive of Ash. | Quality of the Coke produced. |
|---------|-------------------|--|-----------|---------|-----------|----------|-------|---------------------------------|---|-----------|---------|-----------|-----------------------------------|--|
| | | Carbon. | Hydrogen. | Oxygen. | Nitrogen. | Sulphur. | Ash. | | Carbon. | Hydrogen. | Oxygen. | Nitrogen. | | |
| 1* | 1.265 | 82.42 | 4.50 | 11.61 | 0.43 | 1.21 | 0.74 | 4.75 | 83.29 | 4.55 | 11.73 | 0.44 | 47.70 | Caked. { Coke described as like the coal itself, so that not even fritting could have occurred. |
| 2 | 1.300 | 80.25 | 4.01 | 10.99 | 0.49 | 2.99 | 1.57 | 5.91 | 83.83 | 4.19 | 11.47 | 0.51 | 69.59 | |
| 3 | 1.298 | 76.59 | 4.12 | 12.67 | 0.33 | 0.81 | 6.00 | 5.07 | 81.56 | 4.39 | 13.71 | 0.35 | 54.64 | Caked. |
| 4 | 1.378 | 72.35 | 4.17 | 11.99 | 0.62 | 2.65 | 8.33 | 7.15 | 81.18 | 4.67 | 13.47 | 0.68 | 69.73 | Coke crumbly. |
| 5 | 1.311 | 80.49 | 4.10 | 10.62 | 0.20 | 1.10 | 3.64 | 9.11 | 84.36 | 4.30 | 11.13 | 0.21 | 62.40 | Coke slightly fritted. |
| 6 | 1.290 | 81.23 | 4.43 | 9.86 | 0.21 | 0.55 | 4.25 | 4.85 | 84.85 | 4.83 | 10.29 | 0.23 | 63.89 | Caked. |
| 7 | 1.454 | 77.42 | 4.65 | 11.73 | 0.22 | 1.68 | 4.93 | 7.53 | 82.34 | 4.73 | 12.60 | 0.24 | 66.43 | Coke sandy. |
| 8 | 1.275 | 72.27 | 4.16 | 10.73 | 0.34 | 0.88 | 12.50 | 5.06 | 82.59 | 4.76 | 12.26 | 0.39 | 77.29 | Caked. |
| 9 | 1.291 | 75.26 | 4.08 | 10.07 | 0.20 | 1.71 | 3.07 | 6.30 | 78.71 | 4.27 | 16.81 | 0.21 | 77.44 | Caked. |
| 10 | 1.351 | 76.03 | 4.35 | 16.06 | 0.13 | 0.13 | 3.31 | 8.46 | 78.74 | 4.61 | 16.62 | 0.13 | 60.81 | Coke crumbly. |

* 1. From Oberbohnndorf. 2, 3, 8, and 9. From Zwickau. 4, 5, 7, and 10. From Niederwürschnitz. 6. From Planitz.

Accepting the accuracy of Stein's results, it would appear that a caking and a non-caking coal may have the same *ultimate* composition, and, therefore, that the quality of caking may in some cases depend upon *proximate* constitution, that is, upon the *manner* in which the elements, exclusive of those constituting the so-called inorganic or earthy part, are combined.

It is asserted that some coals speedily lose the property of caking after having been drawn from the pit; and the Author is informed by Mr. W. Edmond, of the Mines-Royal Copperworks, that a variety of coal which occurs at Penclawdd, near Swansea, loses its property of caking after exposure to the atmosphere not longer than one or two days. In this case the loss of the caking quality will probably be found to depend on the escape of something from the coal, or on the oxidizing action of the atmosphere upon the coal.

M. de Marsilly states that strongly caking coal, which yielded an excellent coke when fresh from the pit, yielded only an imperfectly formed coke in the same ovens after having been exposed to the air during six months.^a

To the same observer we owe the following observations. He asserts that all caking coals (*houilles grasses*), from pits in which fire-damp occurs, cease to swell up and cake when they have been previously heated to 300° C.; so that when they are heated to redness in a covered crucible in the state of powder, after having been heated to

^a Ann. des Mines. s. 5, 1857, xii. 347 *et seq.*; or the Report upon Marsilly's researches, published in the Comptes rendus for 1858, xlii. 862 *et seq.*

300° C., they will be found in the state of powder afterwards. I have confirmed the correctness of this assertion with respect to the strongly caking coal of Newcastle-on-Tyne. The powder of this coal was heated in the hot-air bath at a temperature ranging between 300° C. and about 304° C. It may be thus heated for about a quarter of an hour without sensibly losing its property of swelling up and caking; but when it is kept exposed to this temperature during one or two hours, it does not swell up when subsequently heated to redness, and yields only a very slightly fritted coke. M. de Marsilly infers that the loss of the caking property by exposure to the air during a long time, and to the action of heat under 330° C. during a short time, is due to the same cause—the volatilization of matter, upon which, he believes, the property of caking depends.

In some instances the caking of a coal depends on the manner in which it is heated and the degree of heat to which it is subjected. Thus the South Staffordshire coals (Nos. 26-29 in the Table, p. 325) are practically non-caking coals; that is, the powder of these coals when heated to redness in the usual way does not yield a coherent coke, but only a very slightly fritted and tender mass. Yet if it be *rapidly* exposed to a *high* temperature, such as a bright red-heat, in a close vessel, a pretty solid hard coke may be obtained. For the knowledge of this fact I am indebted to my friend the late Mr. S. H. Blackwell, of Dudley, and I witnessed the following experiment at the Russell's Hall Ironworks, of which he was then proprietor. A Hessian crucible, 5 inches deep, was nearly filled with powdered Thick-coal slack, which was pressed well down and then plastered over with wet clay. In this state the crucible was put into Jones's coke-oven, described at pp. 438-444, through one of the holes at the back, and there exposed to a bright red-heat during twenty minutes or half-an-hour, when it was withdrawn and left to cool. A firm and perfectly solid coke was produced. The exclusion of the air by clay was stated to be essential; and it was this which suggested the experiment of covering the surface of the coal in that oven, as recorded at p. 444. There is an enormous amount of the slack of such coals annually raised in South Staffordshire, and an enormous amount also left underground, which might be turned to profitable account if caking, under the special conditions just mentioned, could be economically conducted.*

When the proportion of inorganic matter in coal is very large, its influence in diminishing, if not in destroying, the caking quality may be readily understood. However, according to Stein, a coal may yield as much as 21.67 per cent. of ash and yet be caking.¹

The property of caking is important with respect to the use of coal in metallurgical operations. Strongly caking coal may soon become

* This is a subject affecting not merely South Staffordshire. According to Mr. Nicholas Wood, "the waste at the Hetton and Black Boy Collieries alone amounted to 160,000 tons of small coal in a year."—

Colliery Guardian, July 6, 1861.

¹ Chemische und chemisch-technische Untersuchung der Steinkohlen Sachsens, p. 93, Nos. 5 and 6 in the Table.

agglomerated in the furnace into a mass so compact as to be, in a greater or less degree, impervious to air, in which case the fire, without poking, would be extinguished, and poking, in many cases, would be impracticable. In the copper-furnaces at Swansea a mixture of caking and non-caking—in other words, *binding* and *free-burning*—coal is used with advantage, the non-caking coal serving effectually to keep the fire *open* to the passage of air: this subject will be considered more at length in the sequel (see p. 349).

FREE-BURNING COAL.—This term is synonymous with non-caking, and is frequently used by practical metallurgists.

CANNEL COAL.

This is a variety of bituminous coal rich in *disposable* hydrogen, whence it is especially valuable as a gas-coal: it burns readily without melting, and emits a copious bright flame. A piece of good cannel coal when ignited will continue to burn for some time. The term cannel is said to be a corruption of candle, and to be applied to coals of this kind because they burn like a candle. They are brown, brown-black, or black, and in fracture uneven or largely conchoidal; some are comparatively tough and others brittle; they do not soil the fingers; there are varieties which are susceptible of a fine polish, and may be wrought into articles of ornament. Common jet is a variety of cannel coal. The term "Parrot" is, it is stated, applied to a cannel coal occurring near Edinburgh, because it burns with a crackling noise.

ANTHRACITE.

This coal is the ultimate product of the conversion of vegetable matter into coal, and usually contains about 90 per cent. of carbon.

The characters by which anthracite may generally be distinguished are as follow:—It is very compact, deep-black both when massive and in powder, bright, occasionally somewhat bronze-like or sub-metallic in lustre, brittle, uneven, or conchoidal in fracture; it does not soil the fingers; it burns with a feebly luminous, smokeless flame, and is much less easily combustible than other kinds of coal; and, when heated, it does not in the least degree sinter; some varieties decrepitate considerably, even when gradually heated.

This property of decrepitating may cause the production of fine particles to such an extent as seriously to check the passage of air through a furnace in which anthracite is used for fuel, even when the air is impelled by a blast engine. It is a property belonging to Welsh anthracite, and to some varieties of it in an extraordinary degree, but not, I am informed, to the anthracite of the United States of America.

There is an American variety which is beautifully iridescent, and which has accordingly been designated "peacock coal." I have a specimen of such anthracite from Pottsville, Pennsylvania, which has been in my collection for more than thirty years without losing its iridescence.

COMPOSITION OF THE DIFFERENT CLASSES OF COAL.

COMPOSITION OF LIGNITE.

We are indebted to Regnault for an excellent memoir on Combustible Minerals, published in 1837, from which is extracted the following instructive table of analyses of lignites of Tertiary origin, classified according to the degree in which their conversion from vegetable tissue has advanced: ²—

TABLE OF TERTIARY LIGNITES.

| Character of the Lignite. | Locality. | Specific Gravity. | Composition, per cent., exclusive of Water only. | | | | Composition, per cent., exclusive of Ash and Water. | | | | Nature of the Coke. |
|----------------------------------|-------------------------|-------------------|--|-----------|----------------------|-------|---|-----------|----------------------|----------------|---------------------------------|
| | | | Carbon. | Hydrogen. | Oxygen and Nitrogen. | Ash. | Carbon. | Hydrogen. | Oxygen and Nitrogen. | Coke per cent. | |
| Perfect lignite ... | 1. Dax, south of France | 1.272 | 70.49 | 5.59 | 18.93 | 4.99 | 74.19 | 5.88 | 19.93 | 49.1 | Pulverulent. |
| | 2. Bouches-du-Rhône | 1.254 | 63.88 | 4.58 | 18.11 | 13.43 | 73.79 | 5.29 | 20.92 | 41.1 | Do. |
| | 3. Hesse-Cassel | 1.351 | 71.71 | 4.85 | 21.67 | 1.77 | 73.00 | 4.93 | 22.07 | 48.5 | Do. |
| | 4. Basse-Alpes | 1.276 | 70.62 | 5.20 | 21.77 | 3.01 | 72.19 | 5.36 | 22.45 | 49.5 | Do. |
| Imperfect lignite | 5. Greece | 1.185 | 61.20 | 5.00 | 24.78 | 9.02 | 67.28 | 5.49 | 27.23 | 38.9 | } Like wood-charcoal. |
| | 6. Cologne | 1.100 | 63.29 | 4.98 | 26.24 | 5.49 | 66.96 | 5.27 | 27.77 | 36.1 | |
| | 7. Usnach (fossil wood) | 1.167 | 56.04 | 5.70 | 36.07 | 2.19 | 57.29 | 5.83 | 36.88 | .. | |
| Lignite passing into bitumen ... | 8. Elbogen, Bohemia | 1.157 | 73.79 | 7.46 | 13.79 | 4.96 | 77.64 | 7.85 | 14.51 | 27.4 | } Intumesced (boersouffle). Do. |
| | 9. Cuba | 1.197 | 75.85 | 7.25 | 12.96 | 3.94 | 78.96 | 7.56 | 13.49 | 39.0 | |
| Asphaltum | 10. Mexico | 1.063 | 79.18 | 9.30 | 8.72 | 2.80 | 81.46 | 9.57 | 8.97 | 9.0 | |

Every specimen analysed by Regnault had been previously heated to 120° C. during half an hour, in order to expel hygroscopic water, which he found was completely removed *in vacuo*, or at a temperature a little above 100° C.

1. Fine-black; powder brown; fracture uneven; lustre feeble; no ligneous texture; particles of it keep their form, and do not stick together or cake when heated.

2. Occurs in limestone: very schistose; pure-black; powder brown; very brilliant; the texture of wood can no longer be recognised, except in less changed portions, which are brown; particles of it keep their form when heated, and do not cake; burns with a very brilliant and smoky flame.

3. Occurs in clay resting on Muschelkalk: the specimen analysed was extremely brilliant; fracture conchoidal; it resembles the finest jet, but is more tender; powder black-brown; particles of it, when

² Recherches sur les Combustibles minéraux; par M. V. Regnault, aspirant-ingénieur des mines. Ann. des Mines, s. 3, 1837, xii. 161-240.

heated, stick a little together, but without fritting, i.e. forming a sensibly agglutinated mass.

4. Occurs in limestone: compact; black; powder clear-brown; lustre fatty; coke slightly intumesced; it may be used in a smith's fire.

5. This lignite is worked on the banks of the river Alpheus, in Elis, Greece: foliated; laminae thick; dull-black; powder brown; presents much indication of vegetable structure, which in some pieces is perfectly preserved; particles of it keep their form when heated. The portion analysed was treated with hydrochloric acid in order to remove carbonate of lime, of which it contained a large quantity.

6. Occurs in thick beds in sand and clay on the banks of the Rhine from Cologne to Bonn: reddish-brown; powder brown-red; friable; ligneous texture very decided.

7. Occurs at Usnach, on the borders of the Lake of Zürich, Switzerland: brown, almost black; powder clear-brown; very hard and cannot be cut, yet with much trouble it can be pounded in a mortar; woody texture still perfect.

8. Occurs as a thick bed in clay, and is used for firing porcelain; blackish-brown; powder reddish-brown; compact; homogeneous, like jet; fracture conchoidal; dull; yields a very light brilliant coke, semi-metallic in lustre; contains 1.77 per cent. of nitrogen.

9. Geological position not certain, but presumed to be Tertiary: velvety-black; lustre very fatty; easily melts when heated, and leaves a very light intumesced coke. Regnault regards this mineral as forming the passage from lignites to bitumen or asphaltum.

10. Its geological position is not known: black; powder black; very brilliant; emits a very strong and disagreeable odour; melts below 100° C.

The composition of lignites from different localities is given in the following table, which has been compiled from various sources:—

TABLE OF LIGNITES FROM VARIOUS LOCALITIES.

| Number. | Locality. | Specific Gravity. | Composition, per cent., exclusive of Water only.* | | | | | | Water per cent. | Coke per cent. | Composition, per cent., exclusive of Sulphur,† Ash, and Water. | | |
|---------|-------------------------------|-------------------|---|-----------|---------|------------|----------|-------|-----------------|----------------|--|-----------|----------------------|
| | | | Carbon. | Hydrogen. | Oxygen. | Nitrogen.† | Sulphur. | Ash. | | | Carbon. | Hydrogen. | Oxygen and Nitrogen. |
| 1 | Bovey, Devonshire | 1.129 | 66.31 | 5.63 | 22.86 | 0.57 | 2.36 | 2.27 | 34.66 | 30.79 | 69.53 | 5.91 | 24.56 |
| 1a | do. | .. | 66.76 | 5.59 | 22.81 | .. | 2.09 | 2.75 | 2.21 | 51.50 | 70.18 | 5.88 | 23.97 |
| 2 | Oedenburg, Hungary | 1.285 | 68.50 | 4.56 | 23.64 | .. | 0.91 | 2.39 | 18.68 | 50.89 | 70.84 | 4.72 | 24.44 |
| 3 | Do. | 1.334 | 68.88 | 4.78 | 22.07 | .. | 1.63 | 4.64 | 17.10 | 46.00 | 71.36 | 5.10 | 23.54 |
| 4 | Bodonspatak, do. ... | 1.327 | 65.94 | 4.26 | 33.23 | .. | 4.27 | 3.30 | 10.84 | 52.60 | 59.88 | 4.56 | 35.56 |
| 5 | Palqita, do. ... | 1.256 | 67.64 | 5.50 | 22.86 | .. | 2.59 | 1.41 | 11.07 | 40.03 | 70.40 | 5.73 | 23.87 |
| 6 | Zaemie, Comorn, do. | 1.347 | 68.36 | 4.56 | 22.16 | .. | 0.57 | 4.35 | 12.60 | 59.56 | 71.90 | 4.79 | 23.31 |
| 7 | Wildshut, Upper Austria | 1.308 | 53.79 | 4.26 | 25.39 | .. | 0.93 | 15.58 | 26.15 | 64.70 | 64.46 | 5.10 | 30.44 |
| 8 | Thallern, Austria... | 1.413 | 49.58 | 3.84 | 22.68 | .. | 4.56 | 19.34 | 22.53 | 63.70 | 65.15 | 5.05 | 29.80 |
| 9 | Gloggnitz, do. ... | 1.364 | 57.71 | 4.49 | 22.14 | .. | 3.12 | 12.54 | 25.15 | 54.40 | 68.42 | 5.33 | 26.25 |
| 10 | Schönfeld, Bohemia | .. | 61.20 | 5.17 | 21.28 | .. | .. | 12.35 | 21.20 | .. | 69.82 | 5.90 | 24.28 |

* The percentage composition, under this head, of Nos. 11a, 11b, 11c, 25a, 28, 29, 30, 31, 32, 33, 34, and 35, is inclusive of water.

† When the proportion of nitrogen is not stated, it is included in that of the oxygen.

‡ Except when the sulphur is not given in the eighth column.

TABLE OF LIGNITES FROM VARIOUS LOCALITIES—continued.

| Number. | Locality. | Specific Gravity. | Composition, per cent., exclusive of Water only.* | | | | | | Water per cent. | Coke per cent. | Composition, per cent., exclusive of Sulphur,† Ash, and Water. | | |
|---------|--|-------------------|---|-----------|---------|------------|----------|-------|-----------------|----------------|--|-----------|----------------------|
| | | | Carbon. | Hydrogen. | Oxygen. | Nitrogen.‡ | Sulphur. | Ash. | | | Carbon. | Hydrogen. | Oxygen and Nitrogen. |
| 11 | Schönfeld, Bohemia | .. | 61.68 | 5.30 | 21.37 | .. | .. | 8.65 | .. | .. | 70.80 | 5.81 | 23.39 |
| 11a | Teplitz, do. | .. | 57.38 | 4.28 | 17.64 | .. | 0.45 | 3.00 | 17.25 | .. | 74.35 | 5.39 | 22.26 |
| 11b | Do. do. | .. | 58.29 | 4.63 | 18.42 | .. | 0.71 | 5.30 | 12.60 | .. | 71.61 | 5.75 | 22.64 |
| 11c | Do. do. | .. | 49.67 | 4.15 | 13.00 | .. | 1.03 | 12.90 | 19.25 | .. | 74.33 | 6.21 | 19.46 |
| 12 | Metzen, Saxony . . . | .. | 58.90 | 5.36 | 21.63 | .. | 6.61 | 7.50 | .. | .. | 68.58 | 6.24 | 25.18 |
| 13 | Do. do. | .. | 62.18 | 5.47 | 18.05 | .. | 9.30 | 5.00 | .. | .. | 72.56 | 6.38 | 21.06 |
| 14 | Rietstedt, Prussia . . | 1.218 | 61.13 | 5.09 | 31.95 | .. | .. | 1.93 | 31.66 | .. | 62.27 | 5.18 | 32.55 |
| 15 | Lüderburg, do. | 1.219 | 55.30 | 4.90 | 31.95 | .. | .. | 7.25 | 49.50 | .. | 69.01 | 5.31 | 34.68 |
| 16 | Touditz, do. | 1.263 | 54.02 | 5.28 | 27.90 | .. | .. | 12.80 | 48.60 | .. | 61.95 | 6.06 | 31.99 |
| 17 | Do. do. | .. | 49.91 | 5.20 | 32.42 | .. | .. | 12.47 | .. | .. | 57.02 | 5.94 | 37.04 |
| 18 | Brumby, do. | 1.263 | 47.78 | 4.28 | 18.42 | .. | .. | 29.52 | 40.60 | .. | 67.79 | 6.07 | 26.14 |
| 19 | Frankfort on the Oder, do. | .. | 59.65 | 4.86 | 26.41 | .. | .. | 9.08 | 16.07 | .. | 65.61 | 5.34 | 29.06 |
| 20 | Wittenberg, do. | .. | 64.07 | 5.03 | 27.55 | .. | .. | 3.35 | 17.26 | .. | 66.29 | 5.20 | 29.51 |
| 21 | Zacherhen, do. | .. | 61.26 | 5.76 | 17.44 | .. | .. | 12.54 | 45.37 | .. | 73.47 | 6.59 | 19.94 |
| 22 | Tiflis, Georgia | .. | 63.34 | 5.67 | 27.95 | .. | .. | 3.04 | .. | .. | 65.34 | 5.85 | 29.81 |
| 23 | Irkutsk, Siberia | .. | 47.48 | 4.56 | 33.03 | .. | .. | 14.95 | .. | .. | 55.81 | 5.36 | 38.83 |
| 24 | Lanbach, Hesse-Darmstadt | .. | 57.28 | 6.03 | 36.10 | .. | .. | 0.59 | .. | .. | 57.62 | 6.07 | 36.31 |
| 25 | Near Cassel, Hesse-Cassel | .. | 62.60 | 5.02 | 26.52 | .. | .. | 5.86 | .. | .. | 66.49 | 5.33 | 28.18 |
| 25a | Hesse-Cassel | .. | 68.19 | 4.42 | 19.19 | .. | 0.71 | 2.65 | 11.45 | 47.50 | 72.48 | 6.16 | 22.37 |
| 26 | Sipp Ingen, Lake Constance | .. | 61.40 | 3.28 | 29.82 | .. | .. | 5.50 | .. | .. | 64.96 | 3.48 | 31.56 |
| 27 | Island of Sardinia . . . | .. | 69.98 | 4.75 | 29.42 | .. | .. | 5.85 | .. | 50.00 | 63.71 | 5.05 | 31.24 |
| 27a | Do. do. | .. | 54.13 | 4.30 | 7.37 | .. | 11.61 | 22.69 | 6.16 | .. | 82.26 | 6.52 | 11.22 |
| 28 | Brit. N. America, Prairie, east of Rocky Mountains | .. | 56.50 | 3.65 | 18.91 | 0.80 | 0.60 | 5.62 | 13.92 | .. | 70.75 | 4.57 | 24.68 |
| 29 | Dracosta Coalfield, Turkey-in-Europe | .. | 50.60 | 3.24 | 14.41 | 0.90 | 0.42 | 15.93 | 14.60 | .. | 73.17 | 4.63 | 22.15 |
| 30 | Do. do. | .. | 47.11 | 3.19 | 15.06 | .. | 0.72 | 14.25 | 19.68 | .. | 72.09 | 4.88 | 23.03 |
| 31 | Do. do. | .. | 46.40 | 3.36 | 12.04 | .. | 2.72 | 15.88 | 19.60 | .. | 75.08 | 5.44 | 19.48 |
| 32 | Do. do. | .. | 46.47 | 3.41 | 15.38 | .. | 0.80 | 15.07 | 18.84 | .. | 71.17 | 5.27 | 22.66 |
| 33 | Do. do. | .. | 46.47 | 3.84 | 12.99 | .. | 1.87 | 18.10 | 16.73 | .. | 73.41 | 6.07 | 20.82 |
| 34 | Do. do. | .. | 45.69 | 4.02 | 12.12 | .. | 2.62 | 19.20 | 16.45 | .. | 73.90 | 6.50 | 19.60 |
| 35 | Sasso Forte, Italy . . . | .. | 64.31 | 4.69 | 12.40 | .. | 1.82 | 8.48 | 8.30 | 56.61 | 79.01 | 5.76 | 15.23 |

* The percentage composition, under this head, of Nos. 11a, 11b, 11c, 25a, 28, 29, 30, 31, 32, 33, 34, and 35, is inclusive of water.

† When the proportion of nitrogen is not stated, it is included in that of the oxygen.

‡ Except when the sulphur is not given in the eighth column. § Exclusive of nitrogen.

1.3 Occurs in the Miocene beds of the Tertiary series: brown; structure fibrous and lamellar; becomes rotten by immersion in water; does not soil the fingers; coke has a semi-metallic lustre; does not swell, and cakes but slightly; ash bulky and red; copper and lead were detected in this coal; it evolves an extremely offensive odour in burning.

1a.4 Lignite, called "board-coal," from a bed about 4 feet thick in the "board-coal seam" at Bovey Tracey. It abounds in the remains of dicotyledonous plants, and is woody in structure. It is said to yield a bright, hard, porous coke; the hygroscopic water was estimated by the loss in weight by drying at 100° C., and the specimen analysed had been previously dried at that temperature. It is stated that there are also twenty seams of what is locally termed "rough

* 1. By F. Vaux, Journ. of the Chem. Soc., 1849, i. 318. municated to the Author by the late Mr. E. Rogers, of Abercarn, near Newport, Monmouthshire.

1a. By Mr. W. Ratcliffe, and com-

coal," with which a large proportion of clay is intimately mixed; a specimen of this variety yielded, after air-drying at 37° C., 52·37 per cent. of coke containing 29·98 per cent. of ash, which contained 0·532 per cent. of phosphoric acid, and of which 65·48 per cent. was insoluble in hydrochloric acid and consisted chiefly of silica. Specimens of the Bovey lignite in my possession have split more or less on exposure to the air. An admirable account by Heer of the fossil flora of the Bovey beds will be found in the 'Transactions of the Royal Society' for 1862, pp. 1039-1086.

2-6¹ are of Tertiary origin. 2. Finely fibrous brown-coal. 3. Not fibrous. 4. Pitch-black; powder brown; lustre of fresh surface often vitreous; structure here and there wood-like; breaks in rhombic pieces. 5. A caking coal; black-brown to light-brown; powder brown; woody structure distinct; hard and difficult to pulverize; it contains a peculiar resin. 6. Black; powder brown; lustre imperfectly fatty; fracture uneven, schistose, often conchoidal or rhombic; no trace of vegetable structure; resists exposure to the air.

7.² Wood-like; the coke was obtained by slow heating; by rapid heating the yield was from 2 to 3 per cent. less. The dry coal absorbed from the atmosphere 10·8 per cent. of water in 24 hours, that is, only 7·3 per cent. less than the total amount expelled by desiccation at 100° C.

8.³ Black-brown; wood-like. The dry coal absorbed from the atmosphere 12·7 per cent. of water in 24 hours.

9.⁴ Wood-like; much fissured. The dry coal absorbed from the atmosphere 15·9 per cent. of water in 24 hours.

10.⁵ Described as brown-coal.

11.⁶ Dark black-brown.

11a-11c.⁷ These specimens were received from Sir Richard Griffith, the veteran Irish geologist. 11a. From the St. Richard Pit. The ash is light, and contains silica, alumina, sesquioxide of iron, and lime; it fuses on platinum wire before the blowpipe into a black substance. 11b. This was labelled "Komotau coal." The ash is light-brown; it contains silica, alumina, sesquioxide of iron, and lime—the last substance in less proportion than in No. 11a; it fuses before the blowpipe. 11c. This was labelled "Eger coal from bore-hole." The loss by desiccation at 110° C. was estimated as water.

12.⁸ Described as brown-coal.

¹ 2-6. By Nendtwich: *Chemisch-technische Untersuchung der vorzüglichen Steinkohlen-Lager Ungarns*. Von Prof. Nendtwich, pp. 32, 33. (Aus dem October-Hefte des Jahrganges 1851 der Sitzungsberichte der math.-naturw. Classe der kaiserl. Akademie der Wissenschaften besonders abgedruckt.)

² 7. By Schrötter; Kennigott's Uebersicht der Resultate Mineralogischer Forschungen für 1850-51 (published

1853), p. 149.

³ 8. By Schrötter; idem, p. 149.

⁴ 9. By Schrötter; idem, p. 149.

⁵ 10. By Baer; idem, p. 151.

⁶ 11. By Köttig; Kennigott's Uebersicht, etc., for 1844-9 (published 1852), p. 258.

⁷ 11a-11c. By C. Tooke, in my laboratory.

⁸ 12. By Gräber; Berzelius' Jahresbericht, 1848, p. 261.

13.⁹ Described as "black-coal" (*Schwarzkohle*). Black variety of brown-coal.

14—18.¹ Brown-coal from the Prussian province of Saxony. 14. "Fossil wood," i.e. presenting wood-like structure. 15, 16, 18. Earthy. In determining the specific gravity and water, coal fresh from the workings was operated upon. *Colour of ash*:—of 14, reddish-white; of 15, yellow-brown; of 16, greyish-white; of 18, greyish-white.

17.² Earthy; from the same locality as No. 16, but the analysis is by another operator.

19—21.³ Described as brown-coal.

22, 23.⁴ Brown-coal.

24.⁵ Wood-like.

25. Brown-coal.

25a.⁶ Ash bright orange-red, easily blown away.

26.⁷ Brown-coal.

27.⁸ Occurs, rather more than half a mile from the sea, at Goneza, province of Iglesias, to the west of Cagliari. An analysis was made at Turin by Abbene and Rossi, and the mineral was also examined at the École des Mines, Paris, and described as black-coal, schistose, and pyritic, yielding a pulverulent coke and very ferruginous ashes. Sir Roderick Murchison informed me that this mineral probably belongs to the true Coal-measures, in which case it presents an interesting illustration of the fact that a coal of the Coal-measures may remarkably resemble a true lignite in composition.

27a.⁹ Since the publication of the first edition of this work I received from a mercantile house in the City, in 1862, a sample of coal from the same locality as No. 27, with a label attached, bearing the inscription, "Iglesias, west of Cagliari, Island of Sardinia." This coal differs widely in composition from that last described and analysed at the École des Mines, and its characters are as follow:—It is tender and easily frangible; black; lustre not bright, yet not dull or earthy; it contains much intermixed shale, and is seamed throughout with thin layers of a substance which effervesced on the addition of an acid, and was therefore regarded as carbonate of lime; it does not cake when heated. The percentage of ash in the best part of the seam was 13.60. In composition there is nothing to distinguish this coal from that of the Carboniferous system.

28, 29.¹ Brought by Dr. Hector. 28. From the Saskatchewan Plains,

⁹ 13. By Gräber; idem, p. 261.

¹ 14—18. By F. Bischof, manager (Oberbedemeister) of the salt-boiling works at Dürrenberg. *Berg- und hüttenmännische Zeitung*, 1850, p. 74; quoted from *Bergwerksfreund*, v. 13.

² 17. By Wagner; idem (foot-note), quoted from *Polyt. Centralbl.* 1847, p. 1496.

³ 19—21. By Baer; Liebzig und Kopp's *Jahresbericht*, 1852, p. 733.

⁴ 22, 23. By Wokrasensky; Kenn-

gott's *Uebersicht*, etc., for 1844—9 (published 1852), p. 256.

⁵ 24, 25. By J. von Liebzig; idem, pp. 257, 258.

⁶ 25a. By C. Tookey, in my laboratory.

⁷ 26. By L. Gmelin; Kennigott's *Uebersicht*, etc., for 1855 (published 1856), p. 117.

⁸ 27. *Ann. des Mines*, s. 4, 1851, xx. 680.

⁹ 27a. By C. Tookey, in my laboratory.

¹ 28, 29. By C. Tookey, in my laboratory.

La Roche Percée, lat. $49^{\circ} 7' N.$, long. $115^{\circ} W.$; Tertiary (?); specimen taken August 1857; analysis made June 1861. Dark-brown, compact, in part wood-like and in part resembling coal of the Carboniferous system; fracture more or less conchoidal. 29. 6-foot seam. From the right bank of the Saskatchewan, at Fort Edmonton, lat. $53^{\circ} 33' N.$, long. $113^{\circ} 20' W.$; Lower Cretaceous (?). Cracked in small pieces during desiccation by exposure to the air, and much resembled coal of the Carboniferous system in appearance.

30—34.² The Dranista coalfield is situated near Kateri or Katerina, on the west side of the Gulf of Salonica. 30. 16-inch vein. Fracture pitch-black; very fissile; powder almost black. 31. Laca vein. Black, rather dull; powder brownish-black. 32. Loftacaria vein. Fracture jet-black; powder almost black. 33. Demolaca vein. Dull black; powder brown. 34. Panaya vein. Easily fissile; powder brown.

35.³ Black, and bright; firm but splintery; fracture uneven; powder almost black.

LIGNITE FROM TRINIDAD.

G. P. Wall, formerly a student of the Royal School of Mines, in the course of an official survey of the geology of the island of Trinidad, collected specimens of lignites which present many points of interest. They have been analysed in my laboratory by C. Tookey. Combustion was effected in a current of oxygen, and desiccation between $100^{\circ} C.$ and $110^{\circ} C.$ The results are as follow:—

COMPOSITION PER CENT.

| | I. | II. | III. | IV. |
|---------------------------|---------------|---------------|---------------|---------------|
| Carbon | 60·13 | 69·53 | 57·38 | 56·19 |
| Hydrogen | 4·14 | 5·36 | 3·74 | 4·14 |
| Oxygen and nitrogen | 10·77 | 15·22 | 17·50 | 17·39 |
| Sulphur | 2·36 | 0·55 | 0·68 | 2·23 |
| Ash | 2·10 | 3·44 | 3·90 | 2·40 |
| Water | 20·50 | 5·90 | 16·80 | 17·65 |
| | <u>100·00</u> | <u>100·00</u> | <u>100·00</u> | <u>100·00</u> |

COMPOSITION, PER CENT., EXCLUSIVE OF SULPHUR, ASH, AND WATER.

| | I. | II. | III. | IV. |
|---------------------------|--------------------|--------------------|--------------------|---------------|
| Carbon | 80·26 | 77·16 | 72·98 | 72·29 |
| Hydrogen | 5·52 | 5·95 | 4·76 | 5·33 |
| Oxygen and nitrogen | 14·22 | 16·89 | 22·26 | 22·38 |
| | <u>100·00</u> | <u>100·00</u> | <u>100·00</u> | <u>100·00</u> |
| Coke % | <u>43·15</u> | <u>54·00</u> | <u>51·80</u> | <u>44·95</u> |

I. This lignite is black; dull in fracture; its powder is brown. When heated in a close vessel, it yields a non-coherent coke.

² 30—34. By W. J. Ward, in my laboratory.

³ 35. By W. J. Ward, in my laboratory.

II. This lignite is black and bright, like good bituminous coal; friable; even in fracture; its powder is dark-brown. It scintillates much when held in a flame; and, when heated, it evolves an odour like petroleum, cakes, and yields a firm coherent coke. Colour of the ash, red.

III. This lignite is black and compact; its fracture is conchoidal and smooth; its powder is brown. It yields a non-coherent coke.

IV. This lignite is black and compact; its fracture is uneven and dull; its powder is brown. It yields a non-coherent coke.

On inspecting the preceding analyses of Trinidad lignites it will be observed that, with the exception of II., all contain a *large proportion of hygroscopic water*, a proportion far exceeding that which is found in any coals of the Carboniferous system. II. presents an example of a so-called lignite which, in respect to physical characters and chemical composition, resembles bituminous coal of the Carboniferous system.

LIGNITE FROM NEW ZEALAND AND FROM TASMANIA.

Lignites from Auckland, New Zealand, and from Tasmania have been analysed in my laboratory by C. Tookey, with the following results:—

COMPOSITION PER CENT.

| | I. | II. |
|----------------|--------------|--------------|
| Carbon | 55.57 | 59.90 |
| Hydrogen | 4.13 | 4.66 |
| Oxygen | 15.67 | 15.99 |
| Nitrogen | 1.15 | 1.08 |
| Sulphur | 0.36 | 0.30 |
| Ash | 9.00 | 4.64 |
| Water..... | 14.12 | 13.43 |
| | <hr/> 100.00 | <hr/> 100.00 |

I. From Auckland. This lignite is black; dull in lustre; its fracture is uneven, and more or less conchoidal; it shows distinct cleavage; brown resin occurs diffused through this lignite in pieces varying in size from a pea to considerable masses.

II. From Tasmania. This specimen was sent by the late Governor Denison. In physical characters this lignite is similar to the last described, and it also contains resin diffused in like manner through its substance.

Accompanying the specimen of lignite from Tasmania was a piece of resin as large as the fist, which was more opaque, and less resembling ordinary varieties of amber in appearance, than that diffused through I. By the action of benzole a portion only dissolves, a gum-like insoluble mass being left, which retains the form and bulk of the original mass. The specimen was analysed after having been dried between 110° and 120° C.; on combustion, the resin gave 81.60 per cent. of carbon and 11.06 of hydrogen.

LIGNITE FROM CEBU, PHILIPPINE ISLANDS.

COMPOSITION PER CENT.

| | | Exclusive of Sulphur, Ash, and Water. |
|---------------------------|---------------|--|
| Carbon | 55.42 | 73.85 |
| Hydrogen | 4.20 | 5.59 |
| Oxygen and nitrogen | 15.48 | 20.56 |
| Sulphur | 2.25 | — |
| Ash | 7.00 | — |
| Water | 15.70 | — |
| | <u>100.00</u> | <u>100.00</u> |

The surface of this lignite, across the bedding, was black; but, parallel to the bedding, here and there brown; its fracture was uneven, more or less conchoidal, and certainly not distinguishable from that of some characteristic bituminous coals of the Carboniferous system. Colour of the ash, grey. The analysis was made in my laboratory by C. Tookey.

LIGNITE FROM KERGUELEN'S LAND, OR DESOLATION ISLAND.

COMPOSITION PER CENT.

| | I. | | II. | |
|---------------------------|--------------------------------|---------------|--|---------------|
| | Exclusive of Ash and Water. | | Exclusive of Sulphur, Ash, and Water. | |
| Carbon | 48.07 | 70.33 | 41.59 | 69.45 |
| Hydrogen | 8.88 | 5.68 | 3.61 | 6.02 |
| Oxygen and nitrogen | 16.95* | 23.94* | 14.68 | 24.53 |
| Sulphur | — | — | 0.57 | — |
| Ash | 17.05 | — | 27.50 | — |
| Water | 14.05 | — | 12.05 | — |
| | <u>100.00</u> | <u>100.00</u> | <u>100.00</u> | <u>100.00</u> |

* Includes sulphur.

This is a remarkably interesting lignite, which I received from the Admiralty, May 1864. It is very tender and brown-black; it has a dull lustre, and is reticulated throughout with grey laminae of a crystalline transparent mineral resembling a zeolite in appearance. Before the blowpipe this mineral intumesces like borax, and afterwards melts. It is decomposed by hydrochloric acid, but without gelatinizing; it contains silica, alumina, lime and water. It was not possible to separate the mineral in a sufficiently pure state for satisfactory analysis. I. gives the composition of the lignite after it had been freed as far as practicable from the associated mineral, but the latter could not be completely separated; and as it contains water not removable at the temperature at which the coal was dried, the proportion of hydrogen in the analyses is too high. II. gives the composition of the lignite in the state in which it was received. The loss caused by drying the coal between 110° and 120° C. was estimated as water. The analyses were made in my laboratory by C. Tookey.

LIGNITE FROM MAJORCA.

COMPOSITION PER CENT.

| | Without Correction for the Carbonic Acid present in the state of, Carbonate of Lime. | After Deduction of the Carbonic Acid present in the state of Carbonate of Lime. | Exclusive of Sulphur, Ash, and Water. |
|------------------------|---|--|--|
| Carbon | 51.61 | 50.72 | 79.67 |
| Hydrogen | 4.11 | 4.11 | 6.34 |
| Oxygen and nitrogen... | 9.06 | 9.95 | 13.99 |
| Sulphur | 7.87 | 7.87 | — |
| Ash | 17.25 | 17.25 | — |
| Water | 10.10 | 10.10 | — |
| | <u>100.00</u> | <u>100.00</u> | <u>100.00</u> |

This lignite is black and dull in lustre, uneven in fracture, and contains fossil shells of the Tertiary series, which are very conspicuous on account of their greyish-white colour. It occurs between beds of light-brown shale. In burning it emits a strong smell of sulphurous acid, though no pyrites can be seen in it, and it yields a grey ash. When boiled with hydrochloric acid, and chloride of barium is added to the filtrate, there is but a small precipitate, not nearly so much as there would be if the sulphur were present in the state of sulphate of lime. The ash effervesces with hydrochloric acid, evolving carbonic acid, which was quantitatively determined and a correction made for it, as recorded in the second column of the analysis. The numerical relations between the carbon, hydrogen, and oxygen, inclusive of nitrogen, in this lignite are the same as exist in some varieties of coal of the Carboniferous system. Proof of this will be found in the sequel in the Tables showing the composition of bituminous coal. The analysis was made by C. Tookey, in my laboratory, November 1864.

LIGNITE FROM ASIA MINOR.

COMPOSITION PER CENT.

| | | Exclusive of Sulphur, Ash, and Water. |
|---------------------------|---------------|--|
| Carbon | 56.69 | 73.64 |
| Hydrogen | 4.36 | 5.66 |
| Oxygen and nitrogen | 15.94 | 20.70 |
| Sulphur | 0.48 | — |
| Ash | 8.80 | — |
| Water | 13.73 | — |
| | <u>100.00</u> | <u>100.00</u> |
| Coke %..... | <u>50.08</u> | |

This lignite occurs in the Tertiary series, near Kirkagatch, Asia Minor. It is black, not bright, and resembles some varieties of coal of the Carboniferous system. It yields a granular and non-coherent coke. Colour of the ash, pinkish grey. It may be regarded

as lignite of superior quality, and might be used with advantage for household purposes, for raising steam, and in various metallurgical operations. I received a considerable quantity of it from my friend Mr. Larking, and tried it in an ordinary domestic fireplace, when I found it to burn well, and produce a cheerful fire. The analysis was made by W. J. Ward, in my laboratory, in 1868.

LIGNITE FROM NICARAGUA.

COMPOSITION PER CENT.

| | I. | | II. | | III. | |
|-------------------------------------|---------------------------------------|--------|--|--------|---------------------------------------|--------|
| | Exclusive of Sulphur, Ash, and Water. | | Exclusive of Sulphur, Ash, Water, etc. | | Exclusive of Sulphur, Ash, and Water. | |
| Carbon | 58.16 | 74.40 | 56.45 | 81.85 | 56.45 | 76.50 |
| Hydrogen | 4.13 | 5.28 | 5.71 | 8.27 | 4.39 | 5.94 |
| Oxygen and nitrogen..... | 15.89 | 20.32 | 6.82 | 9.88 | 12.96 | 17.56 |
| Sulphur..... | 0.63 | — | 2.50 | — | 0.75 | — |
| Ash | 2.95 | — | 16.48 | — | 17.75 | — |
| Water..... | 18.24 | — | 3.63 | — | 7.70 | — |
| Sulphate of protoxide of iron | — | — | 0.74 | — | — | — |
| Iron-pyrites ... | — | — | 7.67 | — | — | — |
| | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Coke % | 44.83 | — | 43.44 | — | 48.96 | — |

I received samples of these lignites from the Admiralty, for examination.

I. This lignite is black, somewhat dull in lustre, and easily breaks between the fingers; its fracture is uneven, showing in some places very thin films of iron-pyrites, and in others brownish-yellow particles of resinous matter. It yields a coke which is not in the least degree coherent. Colour of the ash, white.

II. This lignite is black, dull, hard, splintery, shale-like in structure, and uneven in fracture. It yielded crude oil in sensible quantity by distillation. The total percentage of sulphur amounted to 6.98. The total quantity of ash obtained in the usual way was 23.5 per cent. It yields a slightly coherent coke. Colour of the ash, which is very bulky, red.

III. This lignite is compact, black, rather dull in lustre, uneven and somewhat conchoidal in fracture, and does not soil the fingers. It yields a lustrous, but non-coherent coke. Colour of the ash, pale-red.

The analyses of these coals were made by W. J. Ward, in the Metallurgical Laboratory of the Royal School of Mines, in 1865, 1866, and 1871, respectively.

LIGNITE FROM VENEZUELA.

COMPOSITION PER CENT.

| | | Exclusive of Sulphur, Ash, Water, etc. |
|-------------------------------------|---------------|---|
| Carbon | 42·16 | 66·85 |
| Hydrogen | 3·46 | 5·48 |
| Oxygen and nitrogen | 17·45 | 27·67 |
| Sulphur, in organic combination.. | 3·45 | — |
| Ash..... | 5·69 | — |
| Water | 12·37 | — |
| Bisulphide of iron | 4·78 | — |
| Sulphate of protoxide of iron | 10·64 | — |
| | <u>100·00</u> | <u>100·00</u> |
| Coke % | <u>52·54</u> | |

This coal should certainly be regarded as lignite. It yields a non-coherent coke. Colour of the ash, red. The quantity of ash obtained in the usual way amounted to 14·58 per cent. The total percentage of sulphur was 8·24, of which 3·45 appears to be in a state of combination with the organic substance of the coal. The analysis was made by W. J. Ward, in my laboratory, in 1866.

LIGNITE FROM CHILI.

COMPOSITION PER CENT.

| | | Exclusive of Sulphur, Ash, and Water. |
|---------------------------|---------------|--|
| Carbon | 47·15 | 74·18 |
| Hydrogen | 3·61 | 5·68 |
| Oxygen and nitrogen | 12·80 | 20·14 |
| Sulphur..... | 1·51 | — |
| Ash | 15·58 | — |
| Water | 19·35 | — |
| | <u>100·00</u> | <u>100·00</u> |
| Coke % | <u>47·44</u> | |

I received this lignite from the Admiralty; it occurs near Lota, a coaling depôt on the coast of Chili, about 250 miles south of Valparaiso. It is dull, brownish-black to black, tender, and fissured; and contained small particles of resin interspersed. Fracture uneven. It yields a non-coherent coke. The analysis was made in the Metallurgical Laboratory of the Royal School of Mines, by W. J. Ward, in 1873.

COMPOSITION OF BITUMINOUS COAL AND ANTHRACITE.

In the following tables is presented a selection of analyses of British and foreign bituminous coals and anthracites.

TABLE OF BRITISH CAKING COALS.

| Number. | Locality. | Specific Gravity. | Composition, per cent., exclusive of Water only.* | | | | | | Water per cent. | Coke per cent. | Composition, per cent., exclusive of Nitrogen, Sulphur, Ash, and Water. | | |
|---------|-------------------------|-------------------|---|-----------|---------|------------|----------|------|-----------------|----------------|---|-----------|---------|
| | | | Carbon. | Hydrogen. | Oxygen. | Nitrogen.† | Sulphur. | Ash. | | | Carbon. | Hydrogen. | Oxygen. |
| 1 | Northumberland ... | .. | 78.65 | 4.65 | 13.66 | .. | 0.55 | 2.49 | .. | .. | 80.67 | 4.76 | 14.57† |
| 2 | Ditto ... | .. | 82.42 | 4.82 | 11.11 | .. | 0.36 | 0.79 | .. | .. | 83.09 | 4.86 | 12.06† |
| 3 | Ditto ... | 1.276 | 81.41 | 5.83 | 7.90 | 2.05 | 0.74 | 2.07 | 1.35 | 66.70 | 85.58 | 6.12 | 8.30 |
| 4 | Ditto ... | 1.259 | 78.69 | 6.00 | 10.07 | 2.37 | 1.51 | 1.36 | .. | .. | 83.06 | 6.33 | 10.62 |
| 5 | Nottinghamshire ... | .. | 77.40 | 4.96 | 7.77 | 1.55 | 0.92 | 3.90 | 3.50 | 63.18 | 85.88 | 5.50 | 8.62 |
| 6 | Blaina, South Wales ... | .. | 82.56 | 5.36 | 8.22 | 1.65 | 0.75 | 1.46 | .. | .. | 85.88 | 5.57 | 8.55 |
| 7 | Ditto ... | .. | 83.44 | 5.71 | 5.93 | 1.66 | 0.81 | 2.45 | .. | .. | 87.77 | 6.00 | 6.23 |
| 8 | Ditto ... | .. | 83.00 | 6.18 | 4.68 | 1.49 | 0.75 | 4.00 | .. | .. | 88.53 | 6.59 | 4.88 |

* The water is included in the case of No. 5.

† The nitrogen, when not quantitatively determined, is included in the number indicating oxygen.

‡ Includes nitrogen and sulphur.

1.³ Sent to the Author by the late Mr. Nicholas Wood. The "Seaton Burn Steam-coal;" it is from the same bed as all the Hartleys, viz. West Hartley, Buddle's Hartley, etc. The powder swells up slightly when heated to redness, and forms a coherent coke. In burning, this coal does not stick to the bars like No. 2, and is called "open burning;" but this term is only correct when used comparatively with a coal like No. 2. An average sample for analysis was obtained from a large lump. 2.49 per cent. of ash contained 0.49 per cent. of sulphuric acid (=0.19 sulphur), and 0.39 per cent. of sesquioxide of iron (=0.273 iron). But this quantity of iron requires 0.31 per cent. of sulphur to form pyrites. The excess of sulphur, therefore, beyond what was thus required, is 0.55-0.31 =0.24 per cent.

2.⁴ Also from the late Mr. Nicholas Wood. The "Peareth Gas-coal." It is of the quality called gas-coals, and is the same as the Pelow Main, Felling, Peltree, and other coals of the Tyne. The powder swells up when heated to redness, and forms a coherent coke. 0.74 per cent. of ash contained 0.06 per cent. of sulphuric acid. The ash was reddish-grey, but lighter in tint than that of No. 1, and if it had consisted entirely of sesquioxide of iron, there would not have been sufficient iron to form pyrites with all the sulphur present. Neither No. 1 nor No. 2 contained any appreciable amount of carbonate. Mr. Wood remarks that "it is curious that both these coals are from the same bed; but steam-coal exists north of New-

³ 1. By A. Dick, in my laboratory.

⁴ 2. By A. Dick, in my laboratory.

castle, and the gas-coal south of it, the change taking place nearly in the line of the river, and within a zone of three miles on the north side."

3.⁶ Name of the seam not stated. The coal caked, swelling considerably. Pyrites was visibly present in this coal.

4.⁶ "Low Main Seam," Buddle's Hartley Colliery. Fracture conchoidal; iron-pyrites appeared to be rather copiously disseminated through this coal; chiefly used for steam purposes, for which it is largely exported.

5.⁷ From the Shireoaks Colliery, belonging to the Duke of Newcastle. Ash bulky, and slightly pink in colour.

6.⁸ Ell-vein⁹ coal. 7. Three-quarter-vein coal. 8. Big-vein coal. Mr. Adams, formerly of the Ebbw Vale Ironworks (which are situated in a valley adjoining and parallel to that in which are the Blaina Ironworks), informed me that the Ell-vein and Big-vein are steam-coals with a white ash; and that the Three-quarter-vein is a furnace-coal.

TABLE OF FOREIGN CAKING COALS.

| Number. | Locality. | Specific Gravity. | Composition, per cent., exclusive of water. | | | | | Water per cent. | Coke per cent. | Composition, per cent., exclusive of Sulphur,* Ash, and Water. | | | |
|---------|------------------------------|-------------------|---|-----------|---------|------------|----------|-----------------|----------------|--|-----------|----------------------|--|
| | | | Carbon. | Hydrogen. | Oxygen. | Nitrogen.† | Sulphur. | | | Carbon. | Hydrogen. | Oxygen and Nitrogen. | |
| 9 | Epinae | 1.353 | 81.12 | 5.10 | 11.25 | .. | .. | 2.53 | .. | 83.22 | 5.23 | 11.55 | |
| 10 | Alais, dép. du Gard. | 1.322 | 89.27 | 4.85 | 4.47 | .. | .. | 1.41 | .. | 90.55 | 4.92 | 4.53 | |
| 11 | Rive-de-Gier | 1.298 | 87.45 | 5.14 | 3.83 | 1.70 | .. | 1.78 | .. | 89.04 | 5.23 | 5.73 | |
| 12 | Ditto | 1.288 | 82.04 | 5.27 | 9.12 | .. | .. | 3.57 | .. | 85.08 | 5.46 | 9.46 | |
| 13 | { Céral, dép. de | 1.294 | 75.38 | 4.74 | 9.02 | .. | .. | 10.88 | .. | 84.56 | 5.32 | 10.12 | |
| 13 | { l'Aveyron | | | | | | | | | | | | |
| 14 | Saint-Girons | 1.316 | 72.94 | 5.45 | 17.53 | .. | .. | 4.08 | .. | 76.05 | 5.69 | 18.26 | |
| 15 | Mons. | .. | 85.10 | 5.49 | 7.25 | .. | .. | 2.16 | .. | 86.98 | 5.61 | 7.41 | |
| 16 | Ditto | .. | 80.55 | 5.53 | 9.52 | .. | .. | 4.40 | .. | 84.28 | 5.78 | 9.96 | |
| 17 | Ditto | .. | 86.38 | 4.48 | 6.09 | .. | .. | 3.06 | .. | 89.10 | 4.62 | 6.28 | |
| 18 | Charleroi | .. | 86.47 | 4.68 | 5.30 | .. | .. | 3.55 | .. | 89.68 | 4.85 | 5.50 | |
| 19 | Valenciennes | .. | 84.84 | 5.53 | 6.83 | .. | .. | 2.80 | .. | 87.25 | 5.69 | 7.03 | |
| 20 | Pas-de-Calais | .. | 86.78 | 4.98 | 5.84 | .. | .. | 2.40 | .. | 88.91 | 5.10 | 5.99 | |
| 21 | Hungary | 1.298 | 86.93 | 4.35 | 6.47 | .. | 0.86 | 0.89 | 1.20 | 88.72 | 4.64 | 6.82 | |
| 22 | Ditto | 1.300 | 86.95 | 4.13 | 6.76 | .. | 0.99 | 2.85 | 1.14 | 88.14 | 4.63 | 6.82 | |
| 23 | Ditto | 1.313 | 80.67 | 4.38 | 6.30 | .. | 2.83 | 5.82 | 1.04 | 82.82 | 4.80 | 6.90 | |
| 24 | Ditto | 1.378 | 69.59 | 4.12 | 9.35 | .. | 5.53 | 11.41 | 1.57 | 77.81 | 4.97 | 11.27 | |
| 25 | Ditto | 1.360 | 79.63 | 4.46 | 4.68 | .. | 0.90 | 10.33 | 1.08 | 81.55 | 5.03 | 5.26 | |

* Except when the sulphur is not separately stated.

† The nitrogen, when not quantitatively determined, is included in the number indicating oxygen.

9.¹ Powder brown. Falls to pieces by exposure to the air, in consequence of the iron-pyrites which it contains. It does not increase in volume when heated; coke semi-metallic in lustre and agglutinated, but the form of the original particles of coal from which it has been derived may be easily recognised.

³ 3. By Vaux, Journ. of the Chem. Soc., 1849, i. 319.

⁴ 4. By Taylor, Edinburgh New Phil. Journal, i. 142.

⁵ 5. By C. Tooke, in my laboratory.

⁶⁻⁸ 6-8. By Dr. Noad. Communicated to the Author.

⁹ I have followed the custom of the locality in the use of the words vein and seam, which are synonymous with respect to the mode of occurrence of coal.

¹ 9. By Regnault, Ann. des Mines, s. 3, 1887, xii. 189.

10.¹ Powder black-brown. Coke semi-metallic in lustre, slightly intumesced; the particles of coal from which it has been derived can often be distinguished in it. The coal is regarded as very hard, i.e. difficult to burn, but capable of producing a very high temperature. This coke is said to be excellent for blast-furnaces.

11.² Powder brown. Coke much intumesced. The small coal is in much request for making coke.

12.³ Powder brown. Coke intumesced.

13.⁴ Powder black-brown. Coke semi-metallic in lustre, fritted; the particles stick well together. This coal occurs in lower marls of the Inferior Oolite.

14.⁵ Powder brown. This coal is a very brilliant jet; very hard; conchoidal in fracture; and is used for ornamental purposes. Coke semi-metallic in lustre; brilliant; the particles become rounded, and stick together pretty firmly. It occurs in the Cretaceous formation (*Terrain crétacé*).

15-20.⁶ In all the coke is described as well formed.

21.⁷ From Resicza mine, county of Krassó. Colour pitch-black; lustre fatty, here and there passing into vitreous; fracture very uneven; caking. It occurs in the Lias. Professor Szabo, of Pesth, informed me that this was considered the best coal in Hungary.

22. From Fünfkirchen, county of Baranya. Colour of the coal and of its powder (?) pitch-black; lustre in the direction of the layers fatty, but on the cross-fracture glistening. It is very easily pulverized, and is said not to fall to pieces when exposed to the air, which latter statement is contradicted by Szabo. Strongly caking. It occurs in the Lias.

23. From Fünfkirchen. Colour pure pitch-black; lustre vitreous; compact; difficult to pulverize, yet falls to pieces by exposure to the air, though not to powder. Strongly caking. It occurs in the Lias.

24. From Szabolcs, county of Baranya. Colour of the coal and of its powder (?) pure pitch-black; lustre fatty; easily rubbed to powder between the fingers, and falls to fine powder by exposure to the air. Strongly caking. It occurs in the Lias.

25. From Szabolcs. Colour pitch-black. Compact, difficult to pulverize, resists the action of the air, and does not fall to pieces after several years' exposure. Strongly caking.

¹ 10. By Regnault, *Ann. des Mines*, s. 3, 1837, xii. 185.

² 11. By Regnault, *idem*, p. 196.

³ 12. By Regnault, *idem*, p. 200.

⁴ 13. By Regnault, *idem*, p. 214.

⁵ 14. By Regnault, *idem*, p. 216.

⁶ 15-20. By M. de Marsilly, *Comptes rendus*, 1858, xli. 891.

⁷ 21-25. By Nendtwich, *Chemisch-technische Untersuchung der vorzüglicheren Steinkohlen-Lager Ungarns*, pp. 15 and 22.

TABLE OF BRITISH NON-CAKING COALS.

| Number. | Locality. | Specific Gravity. | Composition, per cent., exclusive of Water only.* | | | | | | Water per cent. | Coke per cent. | Composition, per cent., exclusive of Sulphur, Ash, and Water. | | |
|---|-----------------------------|-------------------|--|-----------|---------|-----------|----------|------|-----------------|----------------|---|-----------|----------------------|
| | | | Carbon. | Hydrogen. | Oxygen. | Nitrogen† | Sulphur. | Ash. | | | Carbon. | Hydrogen. | Oxygen and Nitrogen. |
| <i>Non-caking Coals rich in Oxygen—</i> | | | | | | | | | | | | | |
| 26 | South Staffordshire | .. | 76.12 | 4.83 | 16.72 | .. | 1.00 | 2.33 | .. | .. | 78.46 | 4.96 | 16.58 |
| 27 | Ditto | .. | 77.01 | 4.71 | 16.72 | .. | 0.74 | 1.56 | .. | .. | 78.53 | 4.80 | 16.67 |
| 28 | Ditto | .. | 76.40 | 4.62 | 17.43 | .. | 0.65 | 1.55 | .. | .. | 77.68 | 4.69 | 17.63 |
| 29 | Ditto | .. | 72.13 | 4.32 | 17.11 | .. | 0.54 | 6.44 | .. | .. | 77.33 | 4.67 | 18.00 |
| 30 | Ditto | 1.278 | 78.57 | 5.29 | 12.88 | 1.64 | 0.39 | 1.03 | 11.29 | 67.21 | 79.70 | 5.37 | 14.93 |
| 31 | Ditto | .. | 70.41 | 4.69 | 12.47 | .. | 0.71 | 2.20 | 9.52 | .. | 80.41 | 5.35 | 14.24 |
| 31a | Ditto | .. | 71.13 | 5.01 | 9.67 | 1.68 | 0.81 | 1.36 | 10.46 | .. | 82.91 | 5.83 | 11.26 |
| 31b | Ditto | .. | 71.10 | 5.13 | 10.79 | 1.24 | 1.92 | 2.01 | 7.81 | .. | 81.72 | 5.89 | 12.39 |
| 31c | Ditto | .. | 74.64 | 4.95 | 8.50 | 1.01 | 1.19 | 1.95 | 7.86 | .. | 84.72 | 5.62 | 9.66 |
| 31d | Ditto | .. | 72.35 | 4.65 | 8.66 | 1.31 | 2.37 | 5.40 | 5.26 | .. | 84.48 | 5.42 | 10.10 |
| 32 | St. Helen's, Lancashire | 1.279 | 75.81 | 5.23 | 11.14 | 1.93 | 0.90 | 5.00 | 3.23 | 65.50 | 80.71 | 5.56 | 13.73 |
| 33 | Scotland | .. | 76.08 | 5.31 | 13.33 | 2.09 | 1.23 | 1.96 | .. | .. | 80.33 | 5.60 | 14.07 |
| 34 | Ditto | .. | 80.63 | 5.16 | 10.61 | 1.33 | 0.84 | 1.43 | .. | .. | 83.65 | 5.35 | 11.00 |
| 35 | Ditto | .. | 80.93 | 5.21 | 10.91 | 1.87 | 0.63 | 0.76 | .. | .. | 83.40 | 5.36 | 11.24 |
| <i>Non-caking Coals rich in Carbon—</i> | | | | | | | | | | | | | |
| 36 | Dowlais, South Wales.. | .. | 89.33 | 4.43 | 3.25 | 1.24 | 0.65 | 1.20 | 0.79 | .. | 92.08 | 4.56 | 3.35 |
| 37 | Ditto ditto..... | .. | 88.13 | 4.51 | 2.94 | 1.41 | 1.01 | 2.00 | 0.68 | .. | 92.22 | 4.71 | 3.67 |
| 38 | Ditto ditto..... | .. | 87.62 | 4.34 | 2.82 | 1.13 | 1.07 | 3.32 | 0.68 | .. | 92.75 | 4.69 | 2.66 |
| 39 | Ditto ditto..... | .. | 82.60 | 4.28 | 3.44 | 1.28 | 1.22 | 7.18 | 0.76 | .. | 91.47 | 4.73 | 3.80 |

* The water is included in the cases of Nos. 31, 31a, 31b, 31c, and 31d.

† The nitrogen, when not quantitatively determined, is included in the number indicating oxygen.

‡ Oxygen, inclusive of nitrogen; obtained by deducting the sum of the carbon, hydrogen, and ash, from 100; hence the totals exceed 100 by the amount of sulphur found.

§ Calculated after corrections mentioned on p. 328.

|| Exclusive of nitrogen.

• 26-29.[§] Ten-yard or Thick-coal from the Whyley Colliery, in the vicinity of West Bromwich. This seam consists of ten or more beds, to which special names are applied. No. 26 is "Rooves;" No. 27, "Top-slipper;" No. 28, "White-coal;" and No. 29, "Brasils." No. 29 contains much earthy matter, and is in request for certain reverberatory smelting-furnaces in Birmingham. The powder of each of these coals is brownish-black. The colour of their respective ashes is as follows:—No. 26, reddish-grey; No. 27, yellowish-red; No. 28, yellowish-red; No. 29, reddish-grey. The portion analysed of each coal was dried somewhat above 100° C. Combustion was effected in oxygen. The total amount of sulphur in each coal was determined, as was also the amount of sulphuric acid in the ashes. No. 26 contained a trace of sulphuric acid.

• 26-29. By A. Dick, in my laboratory.

TABULAR VIEW OF THE RELATION BETWEEN THE QUANTITY OF SULPHUR, AND OF IRON, IN THE COALS NUMBERED 26, 27, 28, AND 29 OF THE LAST TABLE.

| Number. | Sulphuric Acid in the Ashes of 100 parts of Coal. | Iron in the Ashes of 100 parts of Coal. | Sulphur required to form Iron-pyrites with the Iron. | Total Sulphur in 100 parts of Coal. | The + and - signs indicate an Excess of Sulphur or otherwise. | Pyrites in 100 parts of Coal, estimating the whole of the Iron as FeS ₂ , except in No. 29, where the Iron is in Excess. |
|---------|---|---|--|-------------------------------------|---|---|
| 26..... | 0·24 | 0·32 | 0·37 | 1·00 | +0·63 | 0·69 |
| 27..... | 0·31 | 0·12 | 0·14 | 0·74 | +0·60 | 0·26 |
| 28..... | 0·33 | 0·03 | 0·034 | 0·55 | +0·52 | 0·064 |
| 29..... | 1·31 | 0·94 | 1·08 | 0·54 | -0·54 | 1·01 |

In calculating the composition of these coals, the following corrections have been made:—Deduction from the weight of ash of the oxygen corresponding to the sulphur present as sulphuric acid, the product of oxidation; deduction of the oxygen of the sesquioxide of iron existing in the ash, except in No. 29, in which a deduction of oxygen from the sesquioxide of iron was made equivalent to the proportion of iron required to form bisulphide with the sulphur in the coal, the sulphur in this case being the reverse of excessive; and in the same number a correction has been made in the ash, by the addition of 2·64 per cent. of carbonic acid (= 0·72 of carbon)—less 0·43 of carbonic acid found in the ash—which was present in the coal as carbonate. Hence the amount of inorganic matter in this coal may be estimated at 7·67, i.e. by the addition of the carbonic acid expelled by incineration to the actual amount of ash obtained, and with the correction for the sulphuric acid and sesquioxide of iron as above stated. The number 7·67 would represent 1·01 of iron-pyrites and 2·64 of carbonic acid, in combination in the 4·02 of fixed residual inorganic matter. The four analyses after these corrections will be as follow:—

COMPOSITION, PER CENT., OF THE COALS NUMBERED 26, 27, 28, AND 29, IN THE TABLE P. 325, AFTER MAKING CORRECTIONS FOR CARBONIC ACID AND IRON-PYRITES.

| Number. | Carbon. | Hydrogen. | Oxygen and Nitrogen. | Sulphur. | Iron-pyrites. | Residue. |
|---------|---------|-----------|----------------------|----------|---------------|----------|
| 26..... | 76·12 | 4·83 | 16·10 | 0·63 | 0·69 | 1·63 |
| 27..... | 77·01 | 4·71 | 16·35 | 0·60 | 0·25 | 1·08 |
| 28..... | 76·40 | 4·62 | 17·23 | 0·52 | 0·064 | 1·17 |
| 29..... | 72·13 | 4·32 | 16·88 | — | 1·01 | 6·66 |

It is no libel on South Staffordshire to assert that this magnificent bed of coal has been most barbarously treated. The pits have generally been worked by contractors, called butties, under the superintendence of viewers, called ground-bailiffs. In consequence of the rapacity and rascality of many of the former, and the ignorance,

inattention, and fraudulent connivance of many of the latter, an enormous amount of coal has been irremediably lost to the nation. Even at the present day (1861) the South Staffordshire colliery-viewers are frequently very imperfectly educated for their responsible duties, and the system of colliery mismanagement which still extensively prevails in this part of the country is a disgrace to the age.¹

30.² Ten-yard coal, near Wolverhampton. It is not stated from what part of the seam the coal analysed was taken. Specific gravity, 1.28. Under ordinary conditions of coking, this coal, which is described as caking by Vaux, is certainly *non-caking*. Coke stated to be very lustrous. Ash very light, bulky, and yellowish-grey.

31.³ Heathen coal, from the Grace Mary Colliery, Rowley-Regis. This seam is between 5 and 6 feet thick, lies at the depth of a few yards below the Ten-yard coal, and is overlaid by the gubbin ironstone, one of the richest and best ores of the district. The coal is black, bright, non-caking, and yields a buff-coloured ash. A sample in powder was prepared for analysis from a large lump, and left exposed to the air wrapped up in paper during about a fortnight. A portion of this powder was analysed without having been previously dried, and the amount of hygroscopic water in

¹ These remarks have excited the ire of certain mine-agents in South Staffordshire, as will appear from the following printed circular, with a copy of which I was favoured:—

— Dudley, April 9, 1864.

"DEAR SIR,—Permit me to call your attention to the enclosed programme, and to earnestly solicit your attendance at the Mine Agents' Conference on the 13th inst. Besides the discussion upon the pillar and stall and long wall modes of getting the thick coal, there will be especial attention called to a most ungenerous paragraph contained in Dr. Percy's (otherwise) important and recent publication on *Metallurgy*, a copy of which is appended. The passage emanating from the pen of so highly scientific and learned a source behoves us, one and all, to give it our most unqualified contradiction, and show, by our attendance at the conference on Wednesday, that we are not deserving of the imputation cast upon us, and that we can resent such an unwarrantable attack. It is proposed to call upon Dr. Percy to expunge this untrue and objectionable paragraph from any future edition the work may go through; and I need hardly say that this resolution should be supported by every one of us.

"I am, dear Sir, yours faithfully,

"HENRY JOHNSON,

"Sec. to the Conference."

I did not publish the statements objected to without mature reflection and

sure evidence of their truth. I will not withdraw a syllable. If, in support of my allegations, any one should desire specific evidence concerning the state of mining in the locality in question at the period to which I referred, he will find it in the official reports of the Government colliery inspectors for the district.

I append an extract from Nendtwich's paper (*Chemisch-technische Untersuchung der vorzüglicheren Steinkohlen-Lager Ungarns*, p. 3) on the state of coal-mining in Hungary, published in 1851, which in former times was equally applicable to Great Britain, and especially to South Staffordshire. "Coal-mining in Hungary is, with few exceptions, managed badly, and contrary to all the principles of rational mining, as it is in the hands of private persons who possess neither the means nor an acquaintance with the requirements of scientific coal-mining. Moreover, there are no definite laws in this country for regulating coal-mining, which is carried on in the most primitive manner, and is left to the uncontrolled discretion of land-owners or their tenants, who, intent only on their present advantage, strive to work out the property entrusted to them by every possible means, to the incalculable injury of posterity."

² 30. By Vaux, *Journ. of the Chem. Soc.*, 1849, i. 328.

³ 31. By C. Tooke, in my laboratory.

another portion of the powder was ascertained. Small particles contained less water than the fine powder of the *same* sample, the percentage being 9.52 and 10.36 in the two, respectively.³

31a, 31b, 31c, 31d.⁴ From the Ward Colliery, Bloxwich, near Walsall. 31a. Yard-coal; colour of the ash, buff. 31b. Four-yard coal (shallow); colour of the ash, reddish-brown. 31c. Four-yard coal (deep); colour of the ash, grey. 31d. Four-foot coal; colour of the ash, grey.

32.⁵ Rushey Park seam. Slightly caking; lustre of coke semi-metallic.

33.⁶ From Ayrshire. 34. Splint coal, Elgin Colliery, Fifeshire (so called from its belonging to Lord Elgin). 35. Five-foot seam, Elgin Colliery.

36.⁷ Upper Four-foot coal, which is about 2 feet 9 inches thick; the best coal at Dowlais. 37. Ras Las: the so-called "brass" (a kind of clay-iron-ore mixed with coaly matter) and iron-pyrites are visibly disseminated through this coal. 38. Bargoed big-coal; seam from 7 to 8 feet thick; the cheapest coal. 39. Tomo yard coal; bad coal for blast-furnaces. All these coals are used in the blast-furnaces at Dowlais, and the Ras Las is also used for forges.

TABLE OF FOREIGN NON-CAKING COALS.

| Number. | Locality. | Specific Gravity. | Composition, per cent., exclusive of Water only. | | | | | Water per cent. | Coke per cent. | Composition, per cent., exclusive of Sulphur,* Ash, and Water. | | |
|---------|--------------------------|-------------------|---|-----------|----------------------|----------|-------|-----------------|----------------|--|-----------|----------------------|
| | | | Carbon. | Hydrogen. | Oxygen and Nitrogen. | Sulphur. | Ash. | | | Carbon. | Hydrogen. | Oxygen and Nitrogen. |
| 40 | Blanzy, France..... | 1.362 | 76.48 | 5.23 | 16.01 | .. | 2.28 | .. | 57.00 | 78.26 | 5.35 | 16.39 |
| 41 | Commentry, do. | 1.319 | 82.72 | 5.29 | 11.75 | .. | 0.24 | .. | 63.40 | 82.92 | 5.30 | 11.78 |
| 42 | Noroy des Vosges | 1.410 | 64.28 | 4.35 | 13.17 | .. | 19.20 | .. | 60.30 | 78.32 | 5.38 | 16.30 |
| 43 | Mons. | .. | 82.91 | 5.22 | 10.13 | .. | 1.74 | .. | 66.96 | 84.38 | 5.31 | 10.31 |
| 44 | Ditto | .. | 82.95 | 5.42 | 10.93 | .. | 0.70 | .. | 63.58 | 83.63 | 5.46 | 11.01 |
| 45 | Valenciennes..... | .. | 90.54 | 3.66 | 2.70 | .. | 3.10 | .. | 93.17 | 93.44 | 3.78 | 2.78 |
| 46 | Pas-de-Calais..... | .. | 82.68 | 4.18 | 4.54 | .. | 8.60 | .. | 87.62 | 90.46 | 4.57 | 4.97 |
| 47 | Charleroi | .. | 90.89 | 3.65 | 3.98 | .. | 1.48 | .. | 91.86 | 92.26 | 3.70 | 4.04 |
| 48 | Ditto | .. | 88.69 | 4.25 | 5.26 | .. | 1.80 | .. | 85.57 | 90.32 | 4.32 | 5.36 |
| 49 | Hungary..... | 1.423 | 73.38 | 3.86 | 11.65 | 0.68 | 10.53 | 3.06 | 76.33 | 82.54 | 4.35 | 13.11 |
| 50 | Ditto | 1.366 | 76.59 | 3.82 | 17.30 | 0.74 | 1.55 | 7.30 | 70.60 | 78.37 | 3.92 | 17.71 |
| 51 | Ditto | 1.317 | 83.77 | 4.95 | 9.48 | 0.20 | 1.60 | 2.66 | 73.11 | 85.29 | 5.05 | 9.66 |
| 52 | Ditto | 1.319 | 79.03 | 4.26 | 13.58 | 0.87 | 2.28 | 3.21 | 69.98 | 81.57 | 4.41 | 14.62 |
| 53 | Near Aix-la-Chapelle ... | 1.343 | 91.45 | 4.18 | 2.12 | .. | 2.25 | .. | 89.40 | 93.56 | 4.28 | 2.16 |

* Except when the sulphur is not separately stated.

³ At the request of the Author the late Mr. Parry subjected a sample of the slack of the Heathen coal to distillation at a low temperature at the Ebbw Vale Iron-works, and found that 1 cwt. 3 qrs. 25 lbs. of it yielded $8\frac{1}{2}$ quarts of oil, i.e. $20\frac{1}{2}$ gallons to the statute ton. By similar treatment he found that 2 cwt. 3 qrs. 21 lbs. of the shale accompanying this coal yielded only $1\frac{1}{2}$ pint of oil. Mr. Parry also found that 2 cwt. of the Thick-coal

slack from the same colliery yielded $5\frac{1}{2}$ quarts of thin, rather foetid, oil, i.e. $13\frac{1}{2}$ gallons to the ton.

⁴ 31a, 31b, 31c, 31d. By C. Tookey, in my laboratory.

⁵ 32. By Vaux, Journ. of the Chem. Soc., 1849, i. 321.

⁶ 33-35. By Rowney, Edinburgh New Phil. Journ., new ser., 1855, ii. 141.

⁷ 36-39. By E. Riley. Communicated to the Author.

40.⁸ During coking the particles stick together a little, but separate under the slightest pressure; they keep their form, being only a little rounded on their edges. This coal burns with a good flame, which only lasts a short time. Coke [in a commercial sense—J. P.] cannot be made with [the slack of?—J. P.] it, but it is esteemed for boilers. It is characterized as a dry coal with a long flame (*houille sèche à longue flamme*).

41.⁹ Powder black-brown. Coke semi-metallic in lustre, grey, nearly white, very brilliant, and only fritted. Regnault describes this as a true cannel coal.

42.¹ Powder brown. It contains much pyrites disseminated through the whole mass. This coal occurs in the New Red Marl, forming the lower part of the Upper Trias (*étage inférieur—marnes irisées*).

43-48.² 43, 44. Coke fritted. 45. Coke in powder. 46. Coke in powder. 47. Coke in powder. 48. Coke hardly coherent.

49-52.³ From the county of Krassó. 49. Colour pitch-black; lustre fatty; non-caking (*Sandkohle*). 50. Grey-black; lustre dull, somewhat fatty; non-caking. 51. Coal and its powder black; lustre fatty. Coke fritted (*Sinterkohle*). 52. Colour black; but little lustre; difficult to powder, and perfectly resists exposure to the air. Coke fritted.

53.⁴ From Rolduc. Powder pure-black; it has the vitreous lustre of compact anthracite and the foliated structure of ordinary coal. It is very little changed in appearance by coking. Regnault regards it as a link between anthracite and bituminous coal.

TABLE OF BRITISH CANNEL COALS.

| Number. | Locality. | Specific Gravity. | Composition, per cent., exclusive of Water only.* | | | | | | Water per cent. | Coke per cent. † | Composition, per cent., exclusive of Sulphur, Ash, and Water. | | | Disposable Hydro- gen per 100 of Carbon |
|---------|-----------------------------|-------------------|--|-----------|---------|-------------|----------|-------|-----------------|------------------|---|-----------|----------------------------|---|
| | | | Carbon. | Hydrogen. | Oxygen. | Nitrogen. ‡ | Sulphur. | Ash. | | | Carbon. | Hydrogen. | Oxygen and Nitrogen. | |
| 54 | Wigan | 1.317 | 84.07 | 5.71 | 7.82 | .. | .. | 2.40 | .. | 59.00 | 85.81 | 5.85 | 8.34 | 5.65 |
| 55 | Ditto | 1.276 | 80.07 | 5.53 | 8.08 | 2.12 | 1.50 | 2.70 | 0.91 | .. | 85.48 | 5.90 | 8.62 | 5.64 |
| 55a. | Ashton-under- Lyne | .. | 83.25 | 5.75 | 5.06 | .. | 0.86 | 3.48 | 1.60 | 63.25 | 88.50 | 6.11 | 5.39 | 6.14 |
| 56 | Tyneside | 1.319 | 78.06 | 5.80 | 3.12 | 1.85 | 2.22 | 8.94 | .. | .. | 89.76 | 6.68 | 3.58 | 6.88 |
| 56a. | Mold, Flintshire .. | .. | 79.87 | 5.78 | 8.09 | .. | 0.67 | 2.85 | 2.84 | 56.60 | 85.20 | 6.17 | 8.63 | 5.97 |
| 56b. | Ditto ditto | .. | 77.81 | 8.47 | 6.32 | .. | 0.71 | 6.01 | 0.68 | 27.92 | 84.03 | 9.15 | 6.82 | 9.88 |
| 56c. | Scotland | .. | 66.44 | 7.54 | 10.84 | 1.36 | 0.84 | 12.98 | .. | .. | 78.44 | 8.90 | 12.66 | 9.33 |
| 56d. | Ditto | .. | 63.10 | 8.91 | 7.25 | .. | 0.96 | 19.78 | .. | 30.23 | 79.61 | 11.24 | 9.15 | 12.68 |

* The water is included in the cases of Nos. 55a, 56a, and 56b.

† The nitrogen, when not quantitatively determined, is included in the number indicating oxygen.

‡ The residue obtained on heating the Boghead coal, No. 56d, cannot properly be termed coke.

§ Exclusive of nitrogen.

⁸ 40. By Regnault, *Ann. des Mines*, s. 3, 1837, xii. 190.

⁹ 41. By Regnault, *idem*, p. 193.

¹ 42. By Regnault, *idem*, p. 210.

² 43-48. By M. de Marsilly, *Comptes rendus*, 1858, xlv. 891.

³ 49-52. By Nendtwich, *Chemisch-technische Untersuchung der vorzüglicheren Steinkohlen-Lager Ungarns*, p. 15.

⁴ 53. By Regnault, *Ann. des Mines*, s. 3, 1837, xii. 184.

54.⁵ Colour black-brown, without lustre; powder black-brown. Coke silvery metallic grey, very brilliant, only fritted. The particles stick together, but keep the form of those of the original coal.

55.⁶ Coke hard, semi-metallic in lustre, swells up, and takes the form of the crucible.

55a.⁷ From the Dukinfield Colliery. This coal is brownish-black, dull in lustre, and uneven and more or less conchoidal in fracture. It yields a firm and lustrous coke, of about the same bulk as the original coal. Colour of the ash, grey.

56.⁸ From the Blaydon Main Colliery, Tyneside. It is often found in connection with the Buddle's Hartley seam, as roof, base, or even interstratified with it. Black, homogeneous, hard, brittle. Fracture conchoidal. Susceptible of a fine polish.

56a.⁹ Smooth cannel, from the Leeswood Green Colliery. When heated in a covered crucible, it loses 43·40 per cent. in weight, and yields a slightly fritted coke, which crumbles easily between the fingers, and consists of agglutinated particles of nearly the same form and size as those of the original coal; its ash is pale-buff. A sample of the coke prepared by the distillation of this coal in retorts yielded 5 per cent. of bulky ash, and contained 0·64 per cent. of sulphur.

56b. "Curly cannel," from the same colliery, and lying immediately under No. 56a. It derives its name from the peculiarity of its fracture, which exhibits curved markings, suggestive, it is presumed, of curls. It yields a chocolate-coloured ash. When heated in a covered crucible, it produces a very large amount of flame, and loses 72·08 per cent. of volatile matter; the coke, which amounted only to 27·92 per cent., is light, slightly fritted, very porous, and easily crumbles by slight pressure between the fingers. This is certainly one of the finest cannel coals I have seen.

56c.¹ Boghead coal, the variety sometimes termed "Methil brown shale." It is stated to yield 90 gallons of oil per ton.² There are two varieties of this coal, both dull in lustre, one brown and the other black (No. 56d).

56d.³ Boghead coal. This is the coal which was the subject of the celebrated trial at Edinburgh previously referred to.

ALBERTITE.

Under the head of cannel coal may be conveniently inserted a notice of the beautiful pitch-like mineral, named albertite, which has been found in Nova Scotia, Australia, and Scotland.

⁵ 54. By Regnault, *idem*, p. 191.

⁶ 55. By Vaux, *Journ. of the Chem. Soc.*, 1849, i. 320.

⁷ 55a. By C. Tooke, in my laboratory.

⁸ 56. By Taylor, *Edinburgh New Phil. Journ.* 1851, l. 145.

⁹ 56a, 56b. By C. Tooke, in my laboratory.

¹ 56c. By T. Anderson, Professor of

Chemistry in the University of Glasgow. Report of the Trial of Mr. and Mrs. Gillespie, of Torbanehill, against Messrs. Russel and Son, Edinburgh, 1853, p. 33.

² Report of the Royal Commission on Coal, 1871, iii. 163.

³ 56d. By the late Professor W. A. Miller.

COMPOSITION, PER CENT., OF ALBERTITE FROM NEW SOUTH WALES AND FROM NOVA SCOTIA.

| | I. | II. |
|---------------------------|---------------|---------------|
| Carbon | 84·13 | 82·67 |
| Hydrogen | 9·23 | 9·14 |
| Oxygen and nitrogen | 6·64 | 8·19 |
| | <u>100·00</u> | <u>100·00</u> |
| Coke % | 25·35 | |

I. From Coal Creek, Cape Paterson, New South Wales. The mineral resembles the albertite of Nova Scotia, but is softer and less bright; it exhibits a conchoidal fracture. The analysis of this mineral was made by C. Tookey, in my laboratory, in 1865.

II. This is the beautiful mineral from Nova Scotia, of which magnificent specimens were shown in the International Exhibition in London in 1862. It is compact, homogeneous, black, very lustrous, conchoidal in fracture, and pitch-like. The analysis was made by Dr. Wetherill. I have a specimen from Ross-shire, which exactly resembles in appearance the albertite of Nova Scotia.

TABLE OF BRITISH AND AMERICAN ANTHRACITES.

| Number. | Locality. | Specific Gravity. | Composition, per cent., exclusive of Water only. | | | | | | Water per cent. | Composition, per cent., exclusive of Ash and Water.* | | |
|---------|----------------------------|-------------------|--|-----------|---------|------------|----------|-------|-----------------|--|-----------|---------|
| | | | Carbon. | Hydrogen. | Oxygen. | Nitrogen.† | Sulphur. | Ash. | | Carbon. | Hydrogen. | Oxygen. |
| 57 | South Wales, near Swansea | 1·348 | 92·56 | 3·33 | 2·63 | .. | .. | 1·59 | .. | 94·05 | 3·38 | 2·57 |
| 58 | South Wales | 1·392 | 90·39 | 3·28 | 2·98 | 0·83 | 0·61 | 1·61 | 2·00 | 93·54 | 3·39 | 3·07 |
| 58a | South Wales, Vale of Neath | .. | 87·02 | 3·14 | 2·16 | 0·90 | 0·67 | 6·11 | .. | 94·27 | 3·40 | 2·33 |
| 59 | Pennsylvania | 1·462 | 90·45 | 2·43 | 2·45 | .. | .. | 4·67 | .. | 94·69 | 2·54 | 2·57 |
| 60 | Ditto | .. | 92·59 | 2·63 | 1·61 | 0·92 | .. | 2·25 | .. | 95·63 | 2·71 | 1·66 |
| 61 | Ditto | .. | 84·98 | 2·45 | 1·15 | 1·22 | .. | 10·20 | .. | 95·94 | 2·77 | 1·29 |

* Also of nitrogen and sulphur when separately determined.

† The nitrogen, when not quantitatively determined, is included in the number indicating oxygen.

57.⁴ Anthracite used at the Ynisedwin blast-furnaces. Powder pure-black.

58.⁵ Bright metallic in lustre. Does not soil the fingers. Burns without smoke.

58a.⁶ I received from Mr. Wareing, of Neath, a specimen of this anthracite, which was said to be incombustible. It decrepitates in an extraordinary degree, and was reduced to absolute dust when put into one of the assay-furnaces in the Metallurgical Laboratory of the Royal School of Mines. It resembles ordinary Welsh anthracite in appearance. It has been suggested to use a mixture of this anthracite and clay for the beds of copper-furnaces.

⁴ 57. By Regnault, Ann. des Mines, Soc., 1849, i. 324.
s. 3, 1837, xii. 183.

⁵ 58a. By Mr. W. Ratcliffe, formerly of Abercarn, Monmouthshire.

⁶ 58. By Vaux, Journ. of the Chem.

59.⁷ From Pottsville, Pennsylvania. Powder pure-black. The sides of the fissures are beautifully iridescent.

60.⁸ From the Lehigh Summit Mine, Pennsylvania. Lustre shining. I received this specimen from Sir C. Lyell.

61.⁹ From Mauch-Chunk, the shipping-place of the Lehigh coal, at the eastern end of the southern anthracite basin. Lustre somewhat glistening; powder black.

COMPOSITION OF VARIOUS BRITISH, COLONIAL, AND FOREIGN COALS.

Numerous analyses of coals from different parts of the world have been made by my private assistants in the Metallurgical Laboratory of the Royal School of Mines since the publication of the first edition of this volume, of which some have been inserted in the tables preceding, and others will now be presented, partly in a tabular form and partly in separate notices. In all the analyses, the loss by short desiccation at about 110° C. was estimated as water: and the coke was obtained by heating the powder of the coal in a covered platinum crucible, over an air-gas flame, until gaseous matter ceased to be evolved. When the name of the colliery is known from which the coal was obtained, it is in every case stated.

MISCELLANEOUS TABLE OF COALS, CHIEFLY BRITISH.

| Number. | Locality. | Composition per cent. | | | | | | Coke per cent. | Composition, per cent., exclusive of Sulphur, Ash, and Water. | | | |
|---------|-------------------|-----------------------|-----------|----------------------|----------|-------|--------|----------------|---|-----------|----------------------|--|
| | | Carbon. | Hydrogen. | Oxygen and Nitrogen. | Sulphur. | Ash. | Water. | | Carbon. | Hydrogen. | Oxygen and Nitrogen. | |
| 62 | Derbyshire | 77.12 | 5.05 | 8.08 | 1.61 | 5.82 | 2.32 | .. | 85.46 | 5.59 | 8.95 | |
| 63 | Ditto | 83.18 | 4.76 | 6.79 | 1.42 | 1.70 | 2.15 | 65.75 | 87.80 | 5.02 | 7.18 | |
| 64 | Lancashire | 75.90 | 5.14 | 10.11 | 0.93 | 2.02 | 5.90 | .. | 83.27 | 5.64 | 11.09 | |
| 65 | Ditto | 74.33 | 5.08 | 9.17 | 2.18 | 2.98 | 6.26 | .. | 83.91 | 5.73 | 10.36 | |
| 66 | Ditto | 80.32 | 5.33 | 7.47 | 2.13 | 2.87 | 1.88 | 63.32 | 86.26 | 5.72 | 8.02 | |
| 67 | North Wales | 78.44 | 5.27 | 8.30 | 0.99 | 2.15 | 4.85 | 61.38 | 85.26 | 5.72 | 9.02 | |
| 68 | Ditto | 81.29 | 4.43 | 6.77 | 0.91 | 2.50 | 4.10 | 63.80 | 87.91 | 4.78 | 7.31 | |
| 69 | South Wales | 80.08 | 5.03 | 5.29 | 3.42 | 5.05 | 1.13 | 64.72 | 88.59 | 5.56 | 8.85 | |
| 70 | Ditto | 75.49 | 4.78 | 6.78 | 1.31 | 10.67 | 1.12 | 60.88 | 86.78 | 5.48 | 7.70 | |
| 71 | Ditto | 86.81 | 4.51 | 2.75 | 1.75 | 3.40 | 0.78 | 82.66 | 92.29 | 4.79 | 2.92 | |
| 72 | Ditto | 82.28 | 5.28 | 5.96 | 1.25 | 4.18 | 1.07 | 66.38 | 87.99 | 5.64 | 6.37 | |
| 73 | Ditto | 87.61 | 4.73 | 3.55 | 1.07 | 2.38 | 0.66 | 79.90 | 91.37 | 4.93 | 3.70 | |
| 74 | Ditto | 87.85 | 4.67 | 3.77 | 1.07 | 2.00 | 0.64 | 79.72 | 91.25 | 4.84 | 3.91 | |
| 75 | Ditto | 84.75 | 4.65 | 5.04 | 0.76 | 3.93 | 0.87 | 76.92 | 89.75 | 4.92 | 5.33 | |
| 76 | Ditto | 84.10 | 4.76 | 3.79 | 1.28 | 5.43 | 0.64 | 76.12 | 90.78 | 5.13 | 4.09 | |
| 77 | Ditto | 86.67 | 4.77 | 4.30 | 0.88 | 2.63 | 0.75 | 76.86 | 90.53 | 4.98 | 4.49 | |
| 78 | Ditto | 86.59 | 4.98 | 4.52 | 0.93 | 2.00 | 0.98 | 73.16 | 90.12 | 5.18 | 4.70 | |
| 79 | Ditto | 88.34 | 4.06 | 3.18 | 0.66 | 2.93 | 0.83 | 87.54 | 92.44 | 4.24 | 3.32 | |
| 80 | Ditto | 88.47 | 4.05 | 2.36 | 0.74 | 3.45 | 0.93 | 88.38 | 93.26 | 4.26 | 2.48 | |
| 81 | Ditto | 86.80 | 4.25 | 3.06 | 0.83 | 4.40 | 0.66 | 84.42 | 92.24 | 4.51 | 3.25 | |
| 82 | Ditto | 88.48 | 3.43 | 3.37 | 0.84 | 3.18 | 0.70 | 89.80 | 92.88 | 3.59 | 3.53 | |
| 83 | Ditto | 90.41 | 3.97 | 2.20 | 0.78 | 1.75 | 0.89 | 89.36 | 93.62 | 4.11 | 2.27 | |
| 84 | Ditto | 84.17 | 4.12 | 2.36 | 2.19 | 6.37 | 0.79 | 84.04 | 92.86 | 4.54 | 2.60 | |
| 85 | Ditto | 89.26 | 3.75 | 3.25 | 0.74 | 1.43 | 1.57 | 90.86 | 92.74 | 3.89 | 3.37 | |
| 86 | Ditto | 88.85 | 4.22 | 3.15 | 1.30 | 1.77 | 0.71 | 87.20 | 92.35 | 4.38 | 3.27 | |
| 87 | Ditto | 85.00 | 3.93 | 2.24 | 2.18 | 5.85 | 0.80 | 87.74 | 93.24 | 4.31 | 2.45 | |
| 88 | Ditto | 78.54 | 3.97 | 1.99 | 3.13 | 11.37 | 1.00 | 86.30 | 92.95 | 4.69 | 2.36 | |

⁷ 59. By Regnault, *Ann. des Mines*, of the Geological Society, 1845, i. 206.
s. 3, 1837, xii. 180.

⁸ 60. By the Author, *Quarterly Journal*

⁹ 61. By the Author, *idem*, p. 204.

MISCELLANEOUS TABLE OF COALS, CHIEFLY BRITISH—continued.

| Number. | Locality. | Composition per cent. | | | | | | Coke per cent. | Composition, per cent., exclusive of Sulphur, Ash, and Water. | | | |
|---------|-------------------|-----------------------|-----------|----------------------|----------|-------|--------|----------------|---|-----------|----------------------|--|
| | | Carbon. | Hydrogen. | Oxygen and Nitrogen. | Sulphur. | Ash. | Water. | | Carbon. | Hydrogen. | Oxygen and Nitrogen. | |
| 89 | South Wales | 89.92 | 4.33 | 2.37 | 0.78 | 1.90 | 0.71 | 86.04 | 83.08 | 4.47 | 2.46 | |
| 90 | Ditto | 89.83 | 4.25 | 2.41 | 0.77 | 3.13 | 0.61 | 83.82 | 83.03 | 4.45 | 2.52 | |
| 91 | Ditto | 82.32 | 4.75 | 4.59 | 1.03 | 6.59 | 0.72 | .. | 89.81 | 5.19 | 5.00 | |
| 92 | Ditto | 86.67 | 5.03 | 4.44 | 1.15 | 1.63 | 1.08 | 71.70 | 90.16 | 5.23 | 4.61 | |
| 93 | Ditto | 85.84 | 4.58 | 5.42 | 1.12 | 1.62 | 1.45 | 79.40 | 88.56 | 4.69 | 6.75 | |
| 94 | Ditto | 91.05 | 2.80 | 1.72 | 0.98 | 2.05 | 1.40 | 93.82 | 95.29 | 2.92 | 1.79 | |
| 95 | Ditto | 89.92 | 3.70 | 2.26 | 0.82 | 1.95 | 1.29 | 92.66 | 93.79 | 3.86 | 2.35 | |
| 96 | Ditto | 88.29 | 3.65 | 2.47 | 0.77 | 3.63 | 1.19 | 92.13 | 93.52 | 3.86 | 2.62 | |
| 97 | Ditto | 87.41 | 4.46 | 2.56 | 1.41 | 3.25 | 0.91 | 83.42 | 92.57 | 4.72 | 2.71 | |
| 98 | Ditto | 89.73 | 4.00 | 1.62 | 0.76 | 2.83 | 1.06 | 88.31 | 94.11 | 4.19 | 1.70 | |
| 99 | Ditto | 86.49 | 3.69 | 3.08 | 0.91 | 4.75 | 1.08 | 89.26 | 92.74 | 3.96 | 3.30 | |
| 100 | Ditto | 86.98 | 4.47 | 3.45 | 0.93 | 3.42 | 0.75 | 80.46 | 91.66 | 4.71 | 3.63 | |
| 101 | Ditto | 90.65 | 4.03 | 2.43 | 0.49 | 1.43 | 0.97 | 89.14 | 93.35 | 4.15 | 2.50 | |
| 102 | Ditto | 86.61 | 3.71 | 3.97 | 0.83 | 3.80 | 1.08 | 88.83 | 91.86 | 3.93 | 4.21 | |
| 103 | Ditto | 88.48 | 3.77 | 3.17 | 0.70 | 2.98 | 0.90 | 87.54 | 92.73 | 3.95 | 3.32 | |
| 104 | Ditto | 86.95 | 4.84 | 4.64 | 0.64 | 2.05 | 0.88 | 76.87 | 90.17 | 5.02 | 4.81 | |
| 105 | Ditto | 85.80 | 4.99 | 4.76 | 1.47 | 2.05 | 0.93 | 73.67 | 89.80 | 5.22 | 4.98 | |
| 106 | Scotland | 75.20 | 5.25 | 10.62 | 0.88 | 2.75 | 5.30 | .. | 81.79 | 5.71 | 12.50 | |
| 107 | Ditto | 76.02 | 5.22 | 10.56 | 0.50 | 1.15 | 6.55 | .. | 82.36 | 5.65 | 11.99 | |
| 108 | Ditto | 78.68 | 5.45 | 10.06 | 0.56 | 2.40 | 2.85 | 57.40 | 83.04 | 5.75 | 11.21 | |
| 109 | Ditto | 76.77 | 4.16 | 11.91 | 0.49 | 1.22 | 5.45 | 58.00 | 82.26 | 4.45 | 13.29 | |
| 110 | Ditto | 70.43 | 4.69 | 10.76 | 0.73 | 3.75 | 9.65 | 55.70 | 81.33 | 5.42 | 13.25 | |
| 111 | Ditto | 70.23 | 4.39 | 11.94 | 0.62 | 2.37 | 10.45 | 56.70 | 80.56 | 5.04 | 14.40 | |
| 112 | Ditto | 73.38 | 4.61 | 10.67 | 0.64 | 2.12 | 8.60 | 55.10 | 82.17 | 5.16 | 12.67 | |
| 113 | Ditto | 76.50 | 5.03 | 11.68 | 0.94 | 2.25 | 3.60 | 62.95 | 81.25 | 5.34 | 13.41 | |
| 114 | Hanover | 82.53 | 4.10 | 10.57 | 2.05 | 17.70 | 13.05 | 60.64 | 78.18 | 6.10 | 15.72 | |
| 115 | Switzerland | 59.16 | 3.78 | 4.97 | 3.48 | 28.13 | 0.48 | 60.24 | 87.13 | 5.56 | 7.31 | |

The analyses numbered 63, 64, 65, 88, 91, 93, 106, 107, 108, 109, 110, 111, 112, and 113, were made by C. Tookey and the remainder by W. J. Ward.

62. Average of a mixture of thirteen different seams, Renishaw Colliery, Chesterfield, Derbyshire.

63. Monkwood Colliery, near Chesterfield, Derbyshire.

64. Main Delf seam, St. Helen's, Lancashire. Colour of the ash, light reddish-brown.

65. Main Delf seam, Ravenhead, Lancashire. Colour of the ash, dark reddish-brown.

66. Best Arley Coal, near Bolton, Lancashire. Coke firm, coherent. Colour of the ash, dark-red.

67. Main-coal, Wrexham, Denbighshire. Coke somewhat lustrous and coherent. Colour of the ash, light-red.

68. Crank-coal, Wrexham, Denbighshire. It is non-caking. Colour of the ash, light-red. This coal is largely composed of the fibrous, charcoal-like stuff, commonly called "mother of coal."

69. Risca Colliery, near Newport, Monmouthshire. Coke firm and coherent. Colour of the ash, greyish-white.

70. Risca Colliery, near Newport, Monmouthshire. Coke firm and coherent. Colour of the ash, greyish-white.

71. Dunraven Colliery, Pontypridd, Glamorganshire. Coke lustrous, firm, and coherent. Colour of the ash, pinkish-grey.

72. Cae-David seam, Tywith Colliery, Llynvi, Bridgend, Glamorganshire. Coke firm and coherent. Colour of the ash, brownish-red.

73. Nine-foot seam, Llynvi, Bridgend, Glamorganshire. Coke light, firm, coherent, dark in colour, and with little lustre. Colour of the ash, greyish-white.

74. Six-foot seam, Llynvi, Bridgend, Glamorganshire. Coke a little more bulky than the coal which produced it. Colour of the ash, pale-pink.

75. Duffryn seam, Llynvi, Bridgend, Glamorganshire. Coke a little more bulky than the original coal. Colour of the ash, red.

76. Cae-David seam, Llynvi, Bridgend, Glamorganshire. Coke a little more bulky than the coal which produced it. Colour of the ash, grey-pink.

77. Yard-seam, Llynvi, Bridgend, Glamorganshire. Coke a little more bulky than the coal which produced it. Colour of the ash, grey-pink.

78. Victoria pit, Llynvi, Bridgend, Glamorganshire. Coke tender. Colour of the ash, red.

79. "Imperial Merthyr" coal, Aberdare, Glamorganshire. Coke partly agglomerated and hard, and partly in powder. Colour of the ash, pale-red.

80. The sample analysed was made from a mixture of equal parts by weight of the Four-foot vein¹ and the Two-foot-nine-inch vein, Bwllfa Colliery, Aberdare, Glamorganshire. Coke dull, partly firm and coherent, and partly in powder. Colour of the ash, grey.

81. "Cory's Merthyr" coal, Aberdare, Glamorganshire. Coke coherent. Colour of the ash, pinkish-white.

82. Steam or smokeless coal, Hirwain, Aberdare, Glamorganshire. Coke dull, firm, in part coherent, and in part only slightly coherent. Colour of the ash, grey.

83. Nine-foot seam, Bute pit, Hirwain, Aberdare, Glamorganshire. Non-caking; the particles only slightly rounded. Colour of the ash, light-reddish.

84. Rhondda Waterfall Colliery, Glyn Neath, Glamorganshire. Coke lustrous, firm, and coherent. Colour of the ash, pinkish-grey.

85. Nine-foot vein, Venalt Colliery, Glynabont, Neath, Glamorganshire. Non-caking. Colour of the ash, light-red.

86. Venalt Colliery, Glynabont, Neath, Glamorganshire. Coke partly firm and coherent, and partly in powder.

87. Venalt Colliery, Glynabont, Neath, Glamorganshire. Coke partly firm, and partly in the state of rounded particles. Colour of the ash, light-red.

¹ I have followed the custom of the locality in the use of the words vein and seam, which are synonymous with respect to the mode of occurrence of coal.

88. Dynevor, near Swansea, Glamorganshire. Colour of the ash, pink. The shaly portion of this coal contained 13·70 % of ash, and the best portion 9·68 %. The use of this coal in locomotives caused much injury to the copper fire-boxes, and to the tubes. This was apparently owing to the large quantity of iron-pyrites which it contained. Sulphate of copper was found in the tubes, and was probably the result of the oxidizing action of the air on the decrepitated iron-pyrites carried forward and deposited in the tubes.

89. Wain-y-coed Colliery, Pontardawe, near Swansea, Glamorganshire. Coke lustrous, coherent, but rather tender. Colour of the ash, red.

90. Primrose Colliery, Pontardawe near Swansea, Glamorganshire. Coke lustrous, coherent, but tender. Colour of the ash, red.

91. Cwm - Tillery, near Newport, Monmouthshire. The coal analysed was a portion of the block in which the immortal frog, shown alive at the International Exhibition of 1862, is *reported* to have been discovered.

92. Nant-y-moel Colliery, Ogmore Valley, Glamorganshire. Coke firm, coherent. Colour of the ash, light-red.

93. Abertillery Colliery, Newport, Monmouthshire.

94. Landshipping Colliery, Haverfordwest, Pembrokeshire. The particles were not altered in form after having been heated in a covered crucible. Colour of the ash, light-red.

95. Nine-foot vein, Pwllfaron Colliery, Glyn Neath, Glamorganshire. Anthracite. Colour of the ash, pale-red.

96. Eighteen-foot vein, Pwllfaron Colliery, Glyn Neath, Glamorganshire. Anthracite. Colour of the ash, pale greyish-red.

97. Graig seam, Blaen Rhondda Colliery, Glamorganshire. Coke light and porous; very little smoke evolved during coking. Colour of the ash, red.

98. Two-foot nine-inch seam, Blaen Rhondda Colliery, Glamorganshire. Non-caking; only slight cohesion between some of the particles. Colour of the ash, red.

99. Upper Four-foot seam, Blaen Rhondda Colliery, Glamorganshire. Non-caking. Flame smokeless. Colour of the ash, red.

100. Graig seam, Dunraven Colliery, Pontypridd, Glamorganshire. Coke light, bulky, porous in concentric layers. Flame slightly smoky. Colour of the ash, red.

101. Two-foot nine-inch seam, Dunraven Colliery, Pontypridd, Glamorganshire. Non-caking. Flame slightly smoky. Colour of the ash, red.

102. Upper Four-foot seam, Dunraven Colliery, Pontypridd, Glamorganshire. Non-caking; slight cohesion between some of the particles. Flame smokeless. Colour of the ash, pale-red.

103. Six-foot seam, Dunraven Colliery, Pontypridd, Glamorganshire. Non-caking; the particles slightly rounded. Colour of the ash, red.

104. Hafod coal, Glamorganshire. Coke light and porous. Flame yellow and smoky. Colour of the ash, red.

105. Rhondda coal, Glamorganshire. Coke light and porous. Flame yellow and smoky. Colour of the ash, red.

106. Five-foot seam, Wellwood Colliery, Dunfermline, Fifeshire. Colour of the ash, light-buff.

107. Splint seam, Wellwood Colliery, Dunfermline, Fifeshire. Colour of the ash, light-yellow.

108. Five-foot seam, Lassodie Colliery, Dunfermline, Fifeshire. Coke friable. Colour of the ash, grey.

109. Splint seam, Lassodie Colliery, Dunfermline, Fifeshire.

110. Lord Moray's steam-coal, Kelty Colliery, near Blair-Adam, Fifeshire. Coke friable. Colour of the ash, grey. It is considered to be a steam-coal of "great power and much endurance," and was said to be in great demand for locomotives.

111. "Bank-coal," Kelty Colliery, near Blair-Adam, Fifeshire. Colour of the ash, grey with a yellowish tinge. It was said to be fit for steam purposes, but to be more in demand as a household coal.

112. Kinglassie Splint-coal, Kelty Colliery, near Blair-Adam, Fifeshire. Colour of the ash, buff. It was reported to be a good steam or household coal.

113. Gin seam, Kelty Colliery, near Blair-Adam, Fifeshire. It is regarded as a highly bituminous, rich, caking coal, and good for producing coal-tar and gas.

114. From Sehnde, Hanover. This coal is in the immediate neighbourhood of a number of petroleum springs, and is said to occur in the Lower Greensand formation. Coke granular, non-coherent. Colour of the ash, pinkish-white.

115. From Courtres, Switzerland. Coke light, bulky, tender, but coherent. Colour of the ash, pale-red.

COAL FROM NOVA SCOTIA AND CAPE BRETON ISLAND.

COMPOSITION PER CENT.

| | I. | | II. | | III. | |
|---------------------|---------------------------------------|--------|---------------------------------------|--------|---------------------------------------|--------|
| | Exclusive of Sulphur, Ash, and Water. | | Exclusive of Sulphur, Ash, and Water. | | Exclusive of Sulphur, Ash, and Water. | |
| Carbon..... | 75.51 | 84.01 | 72.31 | 86.71 | 73.52 | 86.01 |
| Hydrogen | 5.00 | 5.56 | 5.01 | 6.01 | 4.69 | 5.48 |
| Oxygen and nitrogen | 9.37 | 10.43 | 6.07 | 7.28 | 7.27 | 8.51 |
| Sulphur | 1.09 | — | 5.50 | — | 1.23 | — |
| Ash | 5.05 | — | 9.20 | — | 9.40 | — |
| Water | 3.98 | — | 1.91 | — | 3.89 | — |
| | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Coke %..... | 64.94 | ..... | 63.92 | ..... | 71.92 | ..... |

| | IV. | | V. | |
|------------------------|---------------------------------------|--------|---------------------------------------|--------|
| | Exclusive of Sulphur, Ash, and Water. | | Exclusive of Sulphur, Ash, and Water. | |
| Carbon | 75.80 | 85.24 | 63.72 | 87.95 |
| Hydrogen..... | 5.46 | 6.13 | 4.79 | 6.61 |
| Oxygen and nitrogen... | 7.67 | 8.63 | 3.94 | 5.44 |
| Sulphur | 1.99 | — | 6.35 | — |
| Ash | 5.45 | — | 19.95 | — |
| Water | 3.63 | — | 1.25 | — |
| | 100.00 | 100.00 | 100.00 | 100.00 |
| Coke %..... | 59.46 | | 63.11 | |

I. From Springfield, Bay of Fundy. This coal yields a firm, coherent, lustrous coke. Colour of the ash, greyish-white.

II. From Nova Scotia. The sample analysed was prepared from a mixture of equal weights of three different seams of coal. It yields a coherent, but tender coke.

III. From Pictou County, Nova Scotia. I received this coal from the Admiralty. It is black, bright, firm, but interstratified with a few thin layers of dull coal and of "mother of coal." A very thin band of iron-pyrites was visible in one piece. It yields a firm and coherent coke, a little greater in bulk than the original coal. The gases evolved during coking burnt with a yellow luminous but less smoky flame than in the case of IV. Colour of the ash, grey.

IV. From Sydney, Cape Breton Island. I received this coal from the Admiralty. It consists of interstratified layers of bright and dull coal, and contains thin films of iron-pyrites, here and there a little "mother of coal," and white films probably of carbonate of lime in the lines of fracture. It is black, pretty firm, and uneven in fracture across the line of bedding. It yields a loosely coherent coke. The gases evolved during coking burnt with a smoky yellow flame. Colour of the ash, dark-red.

V. From Schooner Pond, Nova Scotia. This is a cannel coal; it is hard, splintery, and dull. It yields a hard, compact, slightly lustrous coke, not exceeding the bulk of the original coal. Colour of the ash, red.

The analyses of I. and II. were made in 1866 and 1872, respectively, and those of III. IV. and V. in 1873, by W. J. Ward, in the Metallurgical Laboratory of the Royal School of Mines.

COAL FROM VANCOUVER'S ISLAND.

COMPOSITION PER CENT.

| | I. | | II. | |
|------------------------|---------------------------------------|--------|---------------------------------------|--------|
| | Exclusive of Sulphur, Ash, and Water. | | Exclusive of Sulphur, Ash, and Water. | |
| Carbon | 72.29 | 85.83 | 69.93 | 80.98 |
| Hydrogen..... | 5.58 | 6.62 | 4.95 | 5.73 |
| Oxygen and nitrogen... | 6.36 | 7.55 | 11.48 | 13.29 |
| Sulphur | 2.62 | — | 0.74 | — |
| Ash | 11.62 | — | 9.70 | — |
| Water | 1.53 | — | 3.20 | — |
| | 100.00 | 100.00 | 100.00 | 100.00 |
| Coke.% | 57.15 | — | 60.08 | — |

| | III. | | IV. | |
|-------------------------|---------------------------------------|--------|---------------------------------------|--------|
| | Exclusive of Sulphur, Ash, and Water. | | Exclusive of Sulphur, Ash, and Water. | |
| Carbon | 70.99 | 82.18 | 73.28 | 81.34 |
| Hydrogen..... | 5.19 | 6.01 | 5.87 | 5.96 |
| Oxygen and nitrogen ... | 10.20 | 11.81 | 11.44 | 12.70 |
| Sulphur | 0.97 | — | 0.51 | — |
| Ash | 9.75 | — | 6.63 | — |
| Water | 2.90 | — | 2.77 | — |
| | 100.00 | 100.00 | 100.00 | 100.00 |
| Coke % | 62.15 | — | 58.80 | — |

I. This coal is bright and black, but intersected in many places by thin films of carbonate of lime; a little "mother of coal" is also present. It does not soil the fingers. Its fracture is uneven. It yields a compact, firm, coherent coke, of about the same bulk as the original coal. The gases evolved during coking burnt with a luminous, smoky flame.

II. Films of carbonate of lime are present in this coal, and in other respects it resembles I.; but its fracture is more lustrous and rather less uneven than in the case of I. Colour of the ash, reddish-brown.

III. This coal closely resembles I., but is rather brighter. Colour of the ash, white.

IV. From Nanaimo. I received this coal from the Admiralty in 1873. It is hard, splintery, and dull black, with a few bright portions. Much intersected by greyish films. It does not soil the fingers. Its fracture is uneven. It yields a compact, moderately firm coke, of about the same bulk as the original coal. The gases evolved during coking burnt with a smoky yellow flame. Colour of the ash, dirty-buff.

The analyses of these coals were made in the Metallurgical Laboratory of the Royal School of Mines, by W. J. Ward, in 1873.

COAL FROM THE UNITED STATES OF COLOMBIA, SOUTH AMERICA.

COMPOSITION PER CENT.

| | I. | | II. | |
|------------------------|---------------------------------------|--------|---------------------------------------|--------|
| | Exclusive of Sulphur, Ash, and Water. | | Exclusive of Sulphur, Ash, and Water. | |
| Carbon..... | 76.45 | 81.86 | 56.66 | 72.65 |
| Hydrogen | 4.88 | 5.22 | 4.08 | 5.23 |
| Oxygen and nitrogen... | 12.06 | 12.92 | 17.25 | 22.12 |
| Sulphur | 0.25 | — | 0.30 | — |
| Ash | 1.25 | — | 2.63 | — |
| Water | 5.11 | — | 19.08 | — |
| | 100.00 | 100.00 | 100.00 | 100.00 |
| Coke %..... | 59.90 | | 48.50 | |

I received samples of these coals from the Admiralty for examination.

I. This is a non-caking coal rich in oxygen. It is black, compact, firm, not bright, and scarcely soils the fingers; no trace of iron-pyrites can be seen in it with the naked eye; it produces a long flame, and may be regarded as valuable fuel for many purposes, such as raising steam, smelting in reverberatory furnaces, etc. It yields a slightly coherent coke. Colour of the ash, pale-grey with a pink tinge. Tested in Thompson's calorimeter (the construction of which will be described in the sequel, in connection with the Concluding Observations on Fuel), the number 13.75 was found, which is believed to indicate the number of pounds of water at 100° C., which 1 pound of it is capable of evaporating.

II. This coal is evidently lignite, properly so called, as far as composition is concerned. It is black and so tender as to be incapable of transport or storage without crumbling; no iron-pyrites can be seen in it with the naked eye. Tested in Thompson's calorimeter, the number 9.90 was found.

The analyses of these coals were made by W. J. Ward, in the Metallurgical Laboratory of the Royal School of Mines, June 1872.

COAL FROM NEW GRANADA AND BRAZIL.

COMPOSITION PER CENT.

| | I. | II. | III. | IV. | V. |
|--------------------------|--------|--------|--------|--------|--------|
| Carbon..... | 59.05 | 49.55 | 64.81 | 60.30 | 56.28 |
| Hydrogen | 4.03 | 3.18 | 4.55 | 4.07 | 3.87 |
| Oxygen and nitrogen..... | 10.54 | 3.47 | 5.93 | 9.37 | 10.74 |
| Sulphur | 0.54 | 2.25 | 2.09 | 4.32 | 0.56 |
| Ash | 16.68 | 39.55 | 21.42 | 18.82 | 16.85 |
| Water | 9.16 | 2.00 | 1.20 | 3.12 | 11.70 |
| | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

COMPOSITION, PER CENT., EXCLUSIVE OF SULPHUR, ASH, AND WATER.

| | I. | II. | III. | IV. | V. |
|--------------------------|---------------|---------------|---------------|---------------|---------------|
| Carbon | 80·21 ... | 88·17 ... | 86·08 ... | 81·77 ... | 79·39 |
| Hydrogen | 5·47 ... | 5·66 ... | 6·04 ... | 5·51 ... | 5·46 |
| Oxygen and nitrogen..... | 14·32 ... | 6·17 ... | 7·88 ... | 12·72 ... | 15·15 |
| | <u>100·00</u> | <u>100·00</u> | <u>100·00</u> | <u>100·00</u> | <u>100·00</u> |
| Coke % | | | | | <u>51·02</u> |

I. From San Geronimo, New Granada. I received this coal from the Brazilian Minister in 1862. It is black, and on fracture is seen to consist of layers, of which some are dull and others bright; and even the same layer may be dull in one part and bright in another. Colour of the ash, nearly white.

II. III. IV. From Brazil. All these samples contained much inter-mixed nodular iron-pyrites; but the portions analysed were freed as far as practicable from that substance. II. and III. are deceptive in external appearance and resemble good coal; they consist of alternate layers of bright and dull coal. All the samples swell during coking, and yield a porous, tender coke; and it is noteworthy that I. should, notwithstanding the large quantity of ash contained in it, when heated in a covered crucible produce a caked mass, tender, however, and easily crumbling between the fingers.

V. From Brazil. This coal is black, and resembles I.; it contains "mother of coal" interstratified with it; it yields a lustrous, slightly coherent coke. Colour of the ash, white. The specific gravity in mass was 1·334 and in powder 1·429.

The analyses of I., II., III., and IV. were made by C. Tookey, and that of V. by W. J. Ward, in the Metallurgical Laboratory of the Royal School of Mines.

COAL FROM SOUTH AFRICA.

COMPOSITION PER CENT.

| | | Exclusive of Sulphur, Ash, and Water. |
|---------------------------|---------------|--|
| Carbon..... | 75·15 | 84·29 |
| Hydrogen | 4·55 | 4·99 |
| Oxygen and nitrogen | 9·56 | 10·72 |
| Sulphur | 0·96 | — |
| Ash | 5·83 | — |
| Water | 3·95 | — |
| | <u>100·00</u> | <u>100·00</u> |
| Coke % | <u>67·88</u> | |

From Stomberg. This coal is black and bright, and much resembles good Welsh anthracite in appearance. It yields a hard, but friable coke. Colour of the ash, brownish-red. The analysis was made in the Metallurgical Laboratory of the Royal School of Mines, by W. J. Ward, in 1872.

COAL FROM THE STRAITS OF MAGELLAN.

COMPOSITION PER CENT.

| | I | | II | |
|----------------|--------|---|--------|---|
| | | Exclusive of Sulphur, Ash, and Water. | | Exclusive of Sulphur, Ash, and Water. |
| Carbon | 80·86 | 87·27 | 74·82 | 84·39 |
| Hydrogen | 5·52 | 5·96 | 4·91 | 5·54 |
| Oxygen | 4·44 | 6·77 | 8·93 | 10·07 |
| Nitrogen | 1·83 | | | |
| Sulphur | 0·74 | — | 0·82 | — |
| Ash | 1·42 | — | 6·98 | — |
| Water | 5·19 | — | 3·54 | — |
| | 100·00 | 100·00 | 100·00 | 100·00 |
| Coke % | 64·4 | | 67·80 | |

I. From two miles west of Sandy Point. This coal is intermixed with "mother of coal." It is black, and its fractured surface is lustrous, jet-like, and somewhat conchoidal. The lustrous portions do not soil the fingers.

II. From Punta Arenas, or Sandy Point. I received this coal from the Admiralty. It presents an uneven surface, and varies from dull to bright. It does not soil the fingers. Its fracture is uneven. It yields a compact coke.

The analysis of I. was made by C. Tookey in 1858, and that of II. by W. J. Ward in 1873, in the Metallurgical Laboratory of the Royal School of Mines.

COAL FROM CHILI.

COMPOSITION PER CENT.

| | | Exclusive of Sulphur, Ash, and Water. |
|---------------------------|--------|--|
| Carbon | 69·87 | 82·10 |
| Hydrogen | 5·51 | 6·47 |
| Oxygen and nitrogen | 9·73 | 11·43 |
| Sulphur | 1·00 | — |
| Ash | 10·07 | — |
| Water | 3·82 | — |
| | 100·00 | 100·00 |
| Coke % | 60·56 | |

I received this coal from the Admiralty; it occurs near Coronel, about 250 miles south of Valparaiso: an analysis of lignite from Lota, on the same coast, has already been given (see p. 321). This coal is hard, black, and lustrous. It does not soil the fingers, and its fracture is uneven. It contains a few small films of carbonate of lime, and small dull patches resembling "mother of coal." It yields

a firm and compact coke, of about the same bulk as the original coal. The analysis was made in the Metallurgical Laboratory of the Royal School of Mines, by W. J. Ward, in 1873.

COAL FROM THE ISLANDS OF LABUAN AND BORNEO.

COMPOSITION PER CENT.

| | I. | II. | III. | IV. | V. |
|---------------------------|---------------|---------------|---------------|---------------|---------------|
| Carbon | 71·66 ... | 72·27 ... | 70·96 ... | 71·56 ... | 77·52 |
| Hydrogen | 5·53 ... | 5·20 ... | 5·57 ... | 5·09 ... | 5·94 |
| Oxygen and nitrogen | 14·66 ... | 14·28 ... | 14·34 ... | 14·47 ... | 12·23* |
| Sulphur | 0·40 ... | 0·30 ... | 1·43 ... | 0·98 ... | 0·71 |
| Ash | 1·95 ... | 1·85 ... | 2·15 ... | 2·45 ... | 3·60 |
| Water | 5·80 ... | 6·10 ... | 5·55 ... | 5·45 ... | — |
| | <u>100·00</u> | <u>100·00</u> | <u>100·00</u> | <u>100·00</u> | <u>100·00</u> |

COMPOSITION, PER CENT., EXCLUSIVE OF SULPHUR, ASH, AND WATER.

| | I. | II. | III. | IV. | V. |
|---------------------------|---------------|---------------|---------------|---------------|---------------|
| Carbon | 78·02 ... | 78·77 ... | 78·09 ... | 78·54 ... | 81·02 |
| Hydrogen | 6·02 ... | 5·67 ... | 6·12 ... | 5·58 ... | 6·20 |
| Oxygen and nitrogen | 15·96 ... | 15·56 ... | 15·79 ... | 15·88 ... | 12·78* |
| | <u>100·00</u> | <u>100·00</u> | <u>100·00</u> | <u>100·00</u> | <u>100·00</u> |
| Coke % | <u>50·70</u> | <u>56·10</u> | <u>52·16</u> | <u>51·02</u> | <u>50·60</u> |

* Inclusive of water.

I. From Labuan. I received this coal from the Admiralty in 1862. It has a fine black colour, and is not unlike Wigan cannel coal in appearance; it occurs as a distinct seam or band in other coal. Its fracture is somewhat conchoidal and bright; it contains particles and occasionally lumps as large as the fist of light-brown resin. It yields a semi-coherent coke. Colour of the ash, buff.

II. From Labuan. I received this coal from the Labuan Coal Company, November 1862. It resembles I., and is obviously the same kind of coal, but is more compact, and presents a more conchoidal fracture.

III. From Labuan. This coal externally resembles I.; but when received, it contained iron-pyrites, ferrous and basic ferric sulphate. It yields a light, lustrous, tender coke. Colour of the ash, pale-red.

IV. From Labuan. This coal presented no visible trace of iron-pyrites or of ferrous or ferric sulphate. It yields a light, lustrous, semi-coherent coke. Colour of the ash, brownish-red.

V. From Semingen (?), near Sarawak, Borneo. This coal is black, and possesses considerable lustre. It yields a very hard, coherent, lustrous coke. Colour of the ash, reddish-yellow.

The analyses of I., II., and V. were made by C. Tookey, and those of III. and IV. by W. J. Ward, in the Metallurgical Laboratory of the Royal School of Mines.

COAL FROM SUMATRA.

COMPOSITION PER CENT.

| | I. | | II. | |
|-------------------------|---------------------------------------|-------------|---------------------------------------|--------|
| | Exclusive of Sulphur, Ash, and Water. | | Exclusive of Sulphur, Ash, and Water. | |
| Carbon | 75.27 ... | 80.54 | 73.04 ... | 80.76 |
| Hydrogen | 5.63 ... | 6.02 | 4.99 ... | 5.52 |
| Oxygen and nitrogen ... | 12.56 ... | 13.44 | 12.41 ... | 13.72 |
| Sulphur | 0.49 ... | — | 1.08 ... | — |
| Ash | 0.83 ... | — | 1.43 ... | — |
| Water | 5.22 ... | — | 7.05 ... | — |
| | 100.00 | 100.00 | 100.00 | 100.00 |
| Coke % | 54.58 | ..... | 55.48 | |

I. From Ranti (?). This coal is hard, homogeneous, black, lustrous, uneven and somewhat conchoidal in fracture, and does not soil the fingers. It yields a coherent coke. Colour of the ash, red.

II. From Soengei Doerian (?). This coal is very similar in external characters to I. It yields a coherent coke. Colour of the ash, red.

Both of these coals are from the same seam, 6 miles apart; they may be regarded as valuable flame-producing coal, and may be applied with advantage in various metallurgical and other operations. The analyses were made in the Metallurgical Laboratory of the Royal School of Mines, by W. J. Ward, in 1872.

COAL FROM QUEENSLAND.

COMPOSITION PER CENT.

| | I. | | II. | |
|-------------------------|---------------------------------------|-------------|---------------------------------------|--------|
| | Exclusive of Sulphur, Ash, and Water. | | Exclusive of Sulphur, Ash, and Water. | |
| Carbon | 68.28 ... | 81.58 | 59.41 ... | 80.84 |
| Hydrogen | 6.34 ... | 7.57 | 4.70 ... | 6.40 |
| Oxygen and nitrogen ... | 9.08 ... | 10.85 | 9.38 ... | 12.76 |
| Sulphur | 0.40 ... | — | 0.50 ... | — |
| Ash | 13.98 ... | — | 22.12 ... | — |
| Water | 1.92 ... | — | 8.89 ... | — |
| | 100.00 | 100.00 | 100.00 | 100.00 |
| Coke % | 50.35 | ..... | 66.36 | |

I. From Rosewood, Kendal County. This coal is dull-black, with bright specks; it is hard, firm, and resisting. It yields a firm, porous, and lustrous coke, of about the same bulk as the original coal. Colour of the ash, pale-red.

II. From Flagstone Creek. This coal is black, and consists of bright and dull layers interstratified; it is easily fissile. It yields a close, firm, compact, and lustrous coke, of about the same bulk as the original coal. Colour of the ash, white.

The analyses of these coals were made in the Metallurgical Laboratory of the Royal School of Mines, by W. J. Ward, in 1873.

COAL FROM NEW SOUTH WALES.

COMPOSITION PER CENT.

| | I | | II | | III | |
|--------------------------|---------------------------------------|--------|---------------------------------------|--------|---------------------------------------|--------|
| | Exclusive of Sulphur, Ash, and Water. | | Exclusive of Sulphur, Ash, and Water. | | Exclusive of Sulphur, Ash, and Water. | |
| Carbon | 77.65 | 83.30 | 65.11 | 79.74 | 75.57 | 88.63 |
| Hydrogen | 4.94 | 5.30 | 4.61 | 5.65 | 4.70 | 5.51 |
| Oxygen and nitrogen ...} | 10.63 | 11.40 | 11.93 | 14.61 | 4.99 | 5.86 |
| Sulphur | 0.58 | — | 0.68 | — | 0.54 | — |
| Ash | 8.25 | — | 7.12 | — | 13.17 | — |
| Water | 2.95 | — | 10.55 | — | 1.03 | — |
| | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Coke % | | | | | | 74.78 |

I. and II. From Cape Paterson. These coals are black, moderately lustrous, firm, and resisting: they were accompanied by the specimen of albertite, of which the analysis is given at p. 331.

III. From Bulli, Cumberland County. This coal is black. It yields a somewhat lustrous, coherent coke. Colour of the ash, reddish-white. The specific gravity was 1.471.

The analyses of I. and II. were made by C. Tookey in 1865, and that of III. by W. J. Ward in 1872, in the Metallurgical Laboratory of the Royal School of Mines.

COAL FROM NEW ZEALAND.

COMPOSITION PER CENT.

| | | Exclusive of Nitrogen, Sulphur, Ash, and Water. |
|----------------|--------|---|
| Carbon | 79.00 | 84.45 |
| Hydrogen | 5.35 | 6.37 |
| Oxygen | 7.71 | 9.18 |
| Nitrogen | 0.89 | — |
| Sulphur | 2.50 | — |
| Ash | 3.50 | — |
| Water | 1.05 | — |
| | 100.00 | 100.00 |
| Coke % | 64.82 | |

From the west coast of the Middle Island. This coal is black, firm, and uneven in fracture. Colour of the ash, remarkably white. Coke contains 2.35 per cent. of sulphur. No sulphuric acid was detected in the hydrochloric acid in which the powder of the coal had been boiled. It would appear that the sulphur was present in the same state of combination in the coal as that in which it exists in albumen, fibrine, etc.; for it could not have been combined with iron, as in that case the ash would have had a decided red colour. Geologists are of opinion that this coal occurs in strata of

Miocene age, in which case it presents an example of a coal similar in external characters and chemical constitution to varieties of coal occurring in the Carboniferous system. The analysis was made in the Metallurgical Laboratory of the Royal School of Mines, by C. Tookey.

COAL FROM INDIA.

COMPOSITION PER CENT.

| | I. | | II. | |
|-------------------------|---------------------------------------|--------|---------------------------------------|--------|
| | Exclusive of Sulphur, Ash, and Water. | | Exclusive of Sulphur, Ash, and Water. | |
| Carbon | 62.30 | 77.37 | 60.92 | 77.84 |
| Hydrogen | 4.73 | 5.87 | 4.17 | 5.84 |
| Oxygen and nitrogen ... | 13.49 | 16.76 | 13.07 | 16.72 |
| Sulphur | 0.81 | — | 0.51 | — |
| Ash | 9.55 | — | 12.65 | — |
| Water | 9.12 | — | 8.68 | — |
| | 100.00 | 100.00 | 100.00 | 100.00 |
| Coke % | 54.74 | | 57.24 | |

I. From Hyderabad, in the Deccan. This coal is black, firm, laminated, uneven in fracture, and resembles many varieties of British coal, such as those of South Staffordshire, Derbyshire, etc. It yields a non-coherent dull coke. Colour of the ash, buff.

II. From Hyderabad, in the Deccan. This coal is similar in external characters to I. It yields a non-coherent dull coke. Colour of the ash, yellowish-white.

Both of these coals may be regarded as valuable fuel for various metallurgical and other purposes. The analyses were made in the Metallurgical Laboratory of the Royal School of Mines, by W. J. Ward, in 1872.

COAL FROM JAPAN.

COMPOSITION PER CENT.

| | | Exclusive of Sulphur, Ash, and Water. |
|---------------------------|--------|---------------------------------------|
| Carbon | 79.26 | 84.43 |
| Hydrogen | 5.86 | 6.24 |
| Oxygen and nitrogen | 8.76 | 9.33 |
| Sulphur | 0.11 | — |
| Ash | 4.51 | — |
| Water | 1.50 | — |
| | 100.00 | 100.00 |
| Coke % | 58.01 | |

From Takasima, in the island of Nifon. I received this coal from the Admiralty in 1873. It is rather tender, somewhat jointed, and shows traces of slickensides. A very thin greenish-grey film was observable on some pieces, and also a few very thin films of iron-pyrites. Its fracture is very uneven, in some places even hackly.

It yields a light, tender, and porous coke. Colour of the ash, pale-red. The analysis was made in the Metallurgical Laboratory of the Royal School of Mines, by W. J. Ward.

My friend C. Tookey, lately Assayer of the Imperial Mint at Osaka, in Japan, has informed me that Japanese coal is used for making coke for the melting furnaces of the Mint, and also as an engine coal for raising steam.

COAL FROM CHINA.

There is good reason for believing that China possesses coal-fields of vast extent, easily workable, and containing different kinds of excellent coal. The subject is one of so much interest and commercial importance to the world as to deserve particular notice even in a treatise on Metallurgy; and the following information respecting it is chiefly derived from an article in the 'Quarterly Review,' bearing the title of "Trade with China."¹

The Chinese coal-fields, it is stated, cover an area exceeding 400,000 square miles. According to the personal observations of a skilful geologist, Baron von Richthofen, in the single province of Hunan there is a coal-field extending over an area of 21,700 square miles, and bearing bituminous coal as well as anthracite. The anthracitic district is most conveniently situated with regard to conveyance by water, it admits of being easily worked, it covers an area as large as the anthracitic coal-field of Pennsylvania, and yields anthracite of the best quality. In the province of Honan the area of the Coal-measures amounts to 10,000 square miles, and in that of Shansi to 30,000 square miles. The aggregate thickness of the coal-bearing strata in the latter province is about 500 feet; the seams of coal vary in thickness from 12 to 30 feet, and are associated with beds of iron ore. A local trade in coal is carried on in the province of Szechuen, in the northern province of Chih-li, in Manchuria, and in most other places where coal is abundant. But the only Chinese mines which can be said to be worked in a business-like manner are those in the island of Formosa, whence, under the stimulus of European aid in mining and shipping appliances, a regular export trade in coal of an inferior quality is carried on with the mainland.

Notwithstanding the richness of China in coal, large supplies of that fuel are imported into the country from America, Japan, and Australia; and the reasons assigned for this are the following:—The existence among the governing class in China of a political objection to mining, which operates with various degrees of force, according to the idiosyncrasies of individual officials, the local customs or traditions of particular districts, etc.; ignorance of the principles of mining and construction of machinery, which confines the Chinese miners in many places to the out-crop of the coal, where the quality is inferior; and, lastly, the absence of efficient means of conveyance.

¹ April 1872, No. 264, cxxxii. 367–393.

Pumpelly, Professor of Mining Engineering at Harvard College, in the United States of America, visited China in 1863, and remained there until 1864, during which period he specially directed his attention to the Chinese coal-fields.² He expresses his belief that there exists throughout China an immense development of Devonian limestone, which rises to the surface in all the important ridges, attaining a thickness in places exceeding 10,000 feet; and that the limestone in almost every part of China is overlaid by a great coal-bearing formation of sandstones, shales, conglomerates, etc., as a rule nearly, if not quite, conformable in stratification to the limestone floor. The fossil plants, however, obtained from this formation have been examined by Dr. Newberry, who considers them to be decidedly supra-carboniferous, and to belong to the Mesozoic period.³ But the data collected at present do not appear to justify the conclusion that all Chinese coal is of that geological age, and the Carboniferous system will probably be found to exist in China. The composition of the coals, to be presently given, favours such probability.

In 1862 I received from the Admiralty samples of three kinds of Chinese coal, which Vice-Admiral Sir James Hope, then commander-in-chief of the squadron on the East India and China station, had sent, with a request that they should be analysed, and which had been tried in Her Majesty's gun-boat *Weasel*, under his orders. The samples were accompanied with a detailed account of the results of that trial, and with information of a commercial character. The analyses were made by C. Tookey, in the Metallurgical Laboratory of the Royal School of Mines, and are reported in the table subjoined. In the remarks following the table the results of the trial above mentioned are incorporated.

COMPOSITION, PER CENT., OF CHINESE COALS.

| | I. | | II. | | III. A. | | III. B. | |
|-------------------------|---------------------------------------|----------|---------------------------------------|----------|---------------------------------------|----------|---------------------------------------|----------|
| | Exclusive of Sulphur, Ash, and Water. | | Exclusive of Sulphur, Ash, and Water. | | Exclusive of Sulphur, Ash, and Water. | | Exclusive of Sulphur, Ash, and Water. | |
| Carbon | 72.27 | ...93.02 | ...85.86 | ...91.54 | ...70.09 | ...83.88 | ...61.90 | ...82.47 |
| Hydrogen ... | 2.00 | ... 2.57 | ... 4.50 | ... 4.82 | ... 4.90 | ... 5.86 | ... 4.58 | ... 6.10 |
| Oxygen and nitrogen ... | 8.42 | ... 4.41 | ... 3.89 | ... 3.64 | ... 8.57 | ...10.26 | ... 8.57 | ...11.43 |
| Sulphur | 0.41 | ... — | ... 0.40 | ... — | ... 0.77 | ... — | ... 0.68 | ... — |
| Ash..... | 19.00 | ... — | ... 5.82 | ... — | ...13.82 | ... — | ...22.62 | ... — |
| Water | 2.90 | ... — | ... 0.53 | ... — | ... 1.85 | ... — | ... 1.65 | ... — |
| | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Coke % | 89.55 | ..... | 83.47 | ..... | 63.15 | ..... | 67.05 | ..... |

² Notice of an Account of Geological Observations in China, Japan, and Mongolia. The American Journal of Science and Arts, s. 2, 1866, xli. 145. See also Pumpelly's volume of travels, Across

America and Asia, etc., 1870.

³ On the Age of the Coal Formation of China. The American Journal of Science and Arts, s. 2, 1866, xlii. 151.

I. This coal is characteristic anthracite; it has a bronzy lustre, and presents an uneven, more or less conchoidal fracture; particles of it suffer no change in form by coking; and the ash is sandy and grey in colour. It was supplied to the *Weasel* at Tientsin, and, "when the steam was raised, was found very good for keeping it up, but the *Weasel* was unable to get steam up with it at all." The price was \$30 per ton, and probably fictitious, owing to a temporary shortness of supply at Tientsin. The locality where it was raised was not ascertained.

II. This coal is black, bright, uneven, and more or less conchoidal in fracture. The colour of the ash is brownish-red. The coke obtained from the dried powder is dull in lustre, pulverulent on the outside, but firm and coherent within. When small bits, or two or three comparatively large pieces of this coal are heated in a covered crucible, they sinter together, and yield a firm, lustrous, coherent mass of coke, 16 per cent. of illuminating gas, exclusive of water, being evolved during the process. It is noteworthy that coal containing so large a proportion of carbon should cake. It is found in the hills to the west of Peking, whence it is conveyed by camels to Tung-chow, about 30 miles, and thence by boat to Taku, about 150 miles. Of this coal 30 tons were supplied to the *Weasel* at Taku, for \$15 per ton, and it was agreed to purchase 130 tons more at the reduced price of \$12 per ton. It proved equal in all respects to the best Welsh coal; it burns clearly without smoke, and produces the same percentage of clinker and ash as Welsh coal. With the best coal supplied to the *Weasel* on the station above mentioned, her tubes required sweeping after the lapse of 24 hours, whereas with this coal she ran three days before sweeping was needed. It was considered probable that a contract might be made for the delivery of a large quantity of this coal at Taku and Shanghai at \$8 per ton or less. The results of the trial in the *Weasel* are precisely such as might have been anticipated from the composition of this coal, which may with certainty be pronounced quite equal, if not somewhat superior, to the best Welsh steam-coal.

III. A. This coal is black, bright, and uneven in fracture. — When heated in a covered crucible, it gives off much illuminating gas, and yields a firm, coherent coke. The colour of the ash is grey.

III. B. This coal resembles III. A. in external characters. It contains much carbonate of lime interspersed, which is not the case with III. A. Notwithstanding the large proportion of inorganic matter, it yields a firm coherent coke. The colour of the ash is grey. III. A. and III. B. were lumps from the same parcel, and, therefore, only varieties of the same kind of coal. This coal is brought from the vicinity of Jehol, in Tartary, but was not supplied in sufficient quantity for trial under steam. It was, however, tried in the galley, and found to produce more smoke than I., but in other respects it promised well. The Chinese *compradore* ⁴

⁴ A Portuguese word, which may be translated purveyor.

stated that he thought it might be supplied at Chefou at \$10 per ton. The mines are supposed to be in the hills near Tsing-ko-ken, in the province of Pechili, and it could probably be brought down and shipped at the mouth of the Lan-mu-ho river with a very short land carriage. A Chinese comprador said he would be prepared to work the mines and supply this coal, if he saw a prospect of procuring a good market for it.

COMPOSITION OF COALS USED IN COPPER-SMELTING AT SWANSEA.

It has been previously stated (see p. 281), that in the smelting-works of Swansea and the neighbourhood, the clinker is allowed to accumulate to such an extent as to form a bed of considerable thickness, and that upon this bed, which is kept sufficiently open to allow of the passage through it of the proper amount of air to sustain combustion, small coal may be effectually burned which would in great measure drop through an ordinary grate composed of bars arranged in the same horizontal plane. It is requisite, therefore, that the inorganic matter of the coals employed should, at the temperature of the furnace, sinter or clot together so as to form a solid coherent clinker, but not actually melt and flow into the ash-pit. Being desirous of ascertaining the composition of the ashes of the coals which produce a suitable clinker, I applied to Mr. William Morgan for average samples of the coals which are consumed at the Hafod Copperworks, of which he directs the smelting department. The samples were promptly supplied, and I have much pleasure in acknowledging the willing assistance which I have at all times received from Mr. Morgan.

Three kinds of coal are used in admixture at the Hafod Works: one *binding*, or caking; and two *free-burning*, or non-caking coals. The mixture consists of the same weight of each of these three coals, viz. 1 part of Mynydd Newydd, or binding coal, 1 of Tyrcenol, and 1 of Pentrefelin, or free-burning coals. The analyses were made in my laboratory by my friend A. Dick. The composition of the ashes of these coals is as follows:—

TABLE SHOWING THE COMPOSITION, PER CENT., OF THE ASHES OF DIFFERENT COALS USED, IN ADMIXTURE, AT THE HAFOD COPPERWORKS, SWANSEA.

| | I. | II. | III. |
|------------------------|---------------|--------------|--------------|
| Silica | 35·05 | 35·04 | 36·15 |
| Alumina | 26·00 | 28·01 | 28·12 |
| Sesquioxide of iron... | 19·56 | 19·06 | 26·26 |
| Lime | 5·80 | 4·53 | 2·28 |
| Magnesia | 1·95 | 2·14 | 1·68 |
| Potash | 2·55 | 2·95 | 1·86 |
| Soda | 0·65 | 0·95 | 0·64 |
| Sulphuric acid | 8·45 | 7·14 | 3·17 |
| | <u>100·01</u> | <u>99·82</u> | <u>99·66</u> |

I. Mynydd Newydd. II. Tyrcenol. III. Pentrefelin. The ashes of each of these coals were exposed separately to a high temperature,

and found to have about the same degree of fusibility. The ash of each coal was reddish, and that of III. most so. The *total sulphur* in each coal was determined by deflagration in a gold crucible, with a mixture of nitre and chloride of sodium; and the *sulphuric acid pre-existing* in the coal in the state of sulphate was determined by digesting the powder of the coal in hydrochloric acid, and proceeding by the addition of a baryta-salt in the usual way. The greater part of the sulphuric acid in the ashes is the product of oxidation during incineration in the presence of strong bases. If we estimate the sulphur—exclusive of that in the sulphuric acid pre-existing in the coal—as existing in combination with iron, as iron-pyrites, the complete analyses of these coals will be as follows:—

TABLE SHOWING THE COMPOSITION, PER CENT., OF THE DIFFERENT COALS USED, IN ADMIXTURE, AT THE HAFOD COPPERWORKS.

| | I. | II. | III. |
|---|-------------|-------------|--------|
| Carbon | 78·87 | 76·81 | 78·49 |
| Hydrogen | 3·73 | 3·42 | 3·73 |
| Oxygen and nitrogen | 8·02 | 5·65 | 4·15 |
| Silica | 5·05 | 4·68 | 4·24 |
| Alumina | 3·75 | 3·74 | 3·29 |
| Sesquioxide of iron | 0·88 | 0·10 | 0·00 |
| Lime | 0·83 | 0·60 | 0·27 |
| Magnesia | 0·28 | 0·28 | 0·19 |
| Potash | 0·36 | 0·39 | 0·16 |
| Soda | 0·09 | 0·12 | 0·07 |
| Sulphuric acid | 0·23 | 0·54 | 0·69 |
| Iron-pyrites { Iron | 1·86 | 1·71 | 2·16 |
| { Sulphur | 1·55 | 1·96 | 2·56 |
| | 100·00 | 100·00 | 100·00 |
| Ash obtained by incineration, } per cent. | 18·37 | 14·34 | 11·73 |

The iron, present in the coals as sesquioxide, probably existed in the intermixed shale.

Le Play has published the following analysis of clinker, reputed of good quality, which, if I mistake not, was procured at the Hafod Works :⁵—

COMPOSITION, PER CENT., OF CLINKER FROM COPPERWORKS, SOUTH WALES.

| | |
|---------------------------|-------|
| Silica | 52·0 |
| Sesquioxide of iron | 5·2 |
| Protoxide of iron | 22·0 |
| Alumina | 14·2 |
| Lime | 2·4 |
| Magnesia | 0·7 |
| Sulphur | 1·3 |
| Iron | 1·0 |
| Carbon | 1·2 |
| | 100·0 |

⁵ Description des Procédés métallurgiques employés dans le Pays de Galles pour la Fabrication du Cuivre, Paris, 1848, p. 122.

The iron of the pyrites present in the coals analysed by Dick, was converted into sesquioxide during incineration; and appears as such in his analyses of the ashes. On the other hand, by far the greater portion of the iron in the clinker analysed by Le Play is stated to have existed as protoxide; the presence of the protoxide of iron will be easily understood from the following considerations:—It is not to be expected that the oxidation of the iron of the pyrites should take place as perfectly on the grate of a furnace as in an analytical operation on the small scale; carbonaceous matter, which has a powerfully deoxidizing action, was found in the clinker; and further, at the temperature at which clinker is formed, sesquioxide of iron would be reduced to protoxide by the action of any free silica present, with the formation of silicate of protoxide. (See the Author's volume on Iron and Steel, p. 100.)

COMPOSITION OF THE ASHES OF COAL.

After what has been stated concerning the source and nature of the inorganic matter in coal at p. 278 *supra*, and the composition of coals used in copper-smelting and of clinker from copperworks at Swansea in the last preceding pages, the following additional tables of analyses will suffice:—

TABLE SHOWING THE COMPOSITION, PER CENT., OF THE ASHES OF LIGNITES.

| | I. | II. | III. | IV. |
|------------------------------|-------------|-------------|-------------|--------|
| Silica | 3·12 | 17·27 | — | 36·01 |
| Alumina | 29·50 | 11·57 | 1·23 | 23·07 |
| Sesquioxide of iron | 32·78 | 5·57* | 20·67 | 5·05 |
| Lime | 20·56 | 23·67 | 45·60 | 15·62 |
| Magnesia | 2·16 | 2·58 | — | 3·64 |
| Potash | 0·99 | 2·64† | 1·67 | 2·38 |
| Soda | 1·72 | — | 1·86 | 0·38 |
| Protoxide of manganese | — | — | — | 1·13 |
| Sulphuric acid | 9·17 | 33·83 | 15·45 | 12·35 |
| Carbonic acid | — | — | 13·52 | — |
| Chlorine | — | — | — | 1·55 |
| | 100·00 | 97·13 | 100·00 | 101·18 |

* With some alumina.

† Carbonate of potash.

I.⁶ From Artern, in Prussian Saxony.II.⁷ From Helmstädt, in Saxony.III.⁸ From Gross-Priessen, in Bohemia.IV.⁹ From Edelény, in Hungary.

The absence of silica from III., and its very small proportion in I., suggest a grave doubt with regard to the accuracy of these two analyses.

* I. By P. Kremers, *De relatione inter carbonos fuscus atque nigros*, Berolini, 1851, p. 15.

† II. By Varrentrap, *Die Physiographie*

der Braunkohle, C. F. Zincken, p. 22.

* III. By O. Köttig, *ibid.*

* IV. By Sonnenschein, *ibid.*

TABLE SHOWING THE COMPOSITION, PER CENT., OF THE ASHES OF BITUMINOUS COALS AND ANTHRACITE.

| Constituents. | I. | II. | III. | IV. | V. | VI. | VII. | VIII. | IX. | X. |
|-----------------------------|-------|-------|-------|--------|--------|-------|-------|--------|--------|--------|
| Silica..... | 35.73 | 24.18 | 37.61 | 39.64 | 40.00 | 53.00 | 37.60 | 43.69 | 53.60 | 55.41 |
| Alumina..... | 41.11 | 20.82 | 38.48 | 39.20 | 44.78 | 25.01 | 52.00 | 39.34 | 39.69 | 18.96 |
| Sesquioxide of iron..... | 11.15 | 26.00 | 14.78 | 11.84 | 12.00 | 3.94 | 3.73 | 8.22 | 5.59 | 16.08 |
| Lime..... | 2.75 | 9.38 | 2.63 | 1.81 | traces | 2.20 | 1.10 | 3.00 | 1.08 | 1.67 |
| Magnesia..... | 2.65 | 9.74 | 2.71 | 2.58 | traces | 2.20 | 1.10 | 3.00 | 1.08 | 1.67 |
| Potash..... | .. | .. | .. | .. | .. | .. | .. | .. | .. | 2.05 |
| Oxide of manganese..... | .. | .. | .. | .. | .. | .. | .. | .. | 0.19 | .. |
| Sulphuric acid..... | 4.45 | 8.37 | 0.29 | traces | 2.22 | 4.89 | 4.14 | .. | .. | 1.73 |
| Phosphoric acid..... | 0.99 | 0.21 | 2.00 | 3.01 | 0.75 | 0.88 | 0.88 | .. | .. | 0.36 |
| Chlorine and soda..... | .. | .. | .. | .. | .. | .. | .. | .. | .. | traces |
| Sulphide of iron (FeS)..... | .. | 0.38 | .. | .. | .. | .. | .. | .. | .. | .. |
| Total..... | 98.83 | 99.08 | 98.40 | 98.08 | 99.75 | 99.92 | 99.45 | 100.00 | 100.01 | 99.64 |

I.-IV.¹ Analyses of the ashes of the Dowlais coals, numbered from 36 to 39 respectively in the table, p. 325.

V.² Rock Vein coal, Pontypool. VI. Four-foot steam-coal, Ebbw Vale. VII. Fordel splint coal, Fifeshire, Scotland.

VIII., IX.³ Anthracites of the United States.

X.⁴ King's Pit (*Königsgrube*) coal, Upper Silesia.

TABLE SHOWING THE COMPOSITION, PER CENT., OF THE ASHES OF FRENCH COALS.⁵

| Constituents. | I. | II. | III. | IV. | V. | VI. | VII. | VIII. |
|----------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|
| Silica..... | 47.30 | 48.85 | 47.10 | .. | .. | .. | .. | .. |
| Alumina..... | 27.30 | 44.90 | 43.35 | .. | .. | .. | .. | .. |
| Sesquioxide of iron..... | 10.00 | 1.40 | 1.15 | 2.20 | 3.98 | 2.40 | 8.30 | 3.69 |
| Lime..... | 6.30 | 0.70 | 0.30 | 1.37 | 0.90 | 1.28 | 0.95 | 1.44 |
| Magnesia..... | 0.90 | 0.70 | 0.30 | 1.93 | 2.30 | 0.73 | 2.55 | 1.64 |
| Sulphur..... | 1.00 | 0.30 | 0.75 | 1.38 | 1.13 | 0.74 | 1.50 | 1.28 |
| Phosphoric acid..... | 1.10 | 0.95 | 1.15 | .. | .. | .. | .. | .. |
| Sulphuric acid..... | 6.10 | 3.00 | 6.20 | 7.15 | 2.98 | 0.87 | 8.00 | 3.64 |
| Constituents not determined..... | .. | .. | .. | 73.10 | 81.10 | 91.90 | 64.40 | 81.10 |
| Insoluble residue..... | .. | .. | .. | .. | .. | .. | .. | .. |
| Total..... | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Percentage of ashes..... | 2.90 | 4.91 | 11.91 | 5.30 | 6.17 | 13.27 | 9.71 | 5.80 |

All that is stated with respect to the localities where the coals were obtained, is that those which yielded I., II., and III. came from one of the French coal-basins, and those which yielded IV., V., VI., and VII. from another. III. was derived from coke from washed coal (*coke de houille lavée*).

¹ I.-IV. By E. Riley. Communicated to the Author.

² V., VI., VII. First Report on the Coals suited to the Steam Navy, by Sir Henry De la Beche and Dr. Lyon Playfair. Museum of Practical Geology, London, 1848.

³ VIII., IX. By Walter R. Johnson: A Report to the Navy Department of the United States on American Coals applicable to Steam Navigation and to

other purposes. Washington, 1844.

⁴ X. By Grundmann, Die Steinkohlen Deutschlands und anderer Länder Europas, etc., 1865, ii. 223.

⁵ Note sur la Présence du Phosphore dans les Cendres de la Houille. Par M. Le Chatelier et M. Léon Durand-Claye. (Extrait du Bulletin de la Société d'Encouragement pour l'Industrie Nationale, Paris, 1873.)

TABLE SHOWING THE COMPOSITION, PER CENT., OF THE ASHES OF AMERICAN COALS.*

| Constituents. | I. | II. | III. | IV. | V. |
|---------------------------|--------|--------|--------|--------|-------|
| Silica | 58.75 | 55.10 | 49.10 | 44.60 | 37.40 |
| Sesquioxide of iron | 2.09 | 13.33 | 3.68 | 7.40 | 9.73 |
| Alumina | 35.30 | 27.10 | 38.90 | 41.10 | 40.77 |
| Lime | 1.20 | 1.85 | 4.53 | 3.61 | 6.27 |
| Magnesia | 0.68 | 0.27 | 0.16 | 1.28 | 1.60 |
| Potash and soda | 1.08 | 1.00 | 1.10 | 1.82 | 1.29 |
| Phosphoric acid | 0.13 | 0.41 | 2.23 | 0.29 | 0.61 |
| Sulphuric acid | 0.24 | 0.68 | 0.07 | 0.58 | 1.99 |
| Sulphur, combined | 0.41 | 0.22 | 0.14 | 0.03 | 0.08 |
| Chlorine | trace. | trace. | trace. | .. | .. |
| Total | 99.88 | 99.86 | 99.61 | 100.71 | 99.64 |
| Percentage of ashes | 5.15 | 7.94 | 3.34 | 2.37 | 7.67 |

WOOD-CHARCOAL.

When wood is heated without access of air to about 300° C.,⁷ it is resolved into volatile products, and a fixed residue or charcoal. The volatile products consist of water, acetic acid, tar, and other matters which are condensable, and of the permanent gases, carbonic acid, carbonic oxide, hydrogen, and carburetted hydrogen. This process of decomposing organic compounds by heat without access of air is termed *dry distillation* or *carbonization*.

GENERAL PROPERTIES OF WOOD-CHARCOAL.

Charcoal is extremely porous, and retains the structure of the wood from which it is derived. It consists essentially of carbon and of the fixed or inorganic matter of wood; but in the case of imperfect carbonization, it may contain a sensible amount of hydrogen and oxygen. Wood may in a great degree be carbonized at 220° C., but not completely below a red-heat.⁸ Good charcoal is black; gives a sonorous ring when struck; breaks with a more or less conchoidal fracture; is easily pulverizable, but does not crumble under moderate pressure; does not sensibly blacken the finger when it is rubbed against a freshly fractured surface, or make a mark which cannot easily be rubbed off; floats on water, and does not burn with flame when ignited in separate pieces. It is a bad conductor of heat and electricity; but its conducting power, for heat at least, is much

* Geological Survey of Ohio. Report of Progress in 1870. Columbia, 1871. Quoted by Le Chatelier and Durand-Claye, *ibid*.

⁷ Wagner's Jahresbericht, 1857, iii. 474.

⁸ I have obtained the following results concerning the temperature at which carbonization may be effected. A narrow test-tube, containing a thin strip of deal, was depressed in mercury to the

depth of an inch or two with the closed end downwards, and the temperature of the mercury was gradually raised. At 220° C. the wood became perceptibly brown, at 240° it became sensibly darker, and at 255° very brown. It was kept for some time at 280°, when it became deep brown-black. At 310° it became very brittle, and could easily be pulverized.

increased after exposure to a high temperature. Thus, one end of a short piece of common charcoal may be held in the hand without inconvenience while the other end is heated; but this cannot be done with impunity with a short piece of charcoal which has been subjected to a high temperature.

COMPOSITION OF WOOD-CHARCOAL.

Faisst has found the composition of several kinds of charcoal to be as follows :⁹—

TABLE SHOWING THE PERCENTAGE COMPOSITION OF WOOD-CHARCOAL.

| | I. | II. | III. |
|---------------------------|-------------|-------------|--------|
| Carbon | 85.89 | 85.18 | 87.43 |
| Hydrogen | 2.41 | 2.88 | 2.26 |
| Oxygen and nitrogen | 1.45 | 3.44 | 0.54 |
| Ash..... | 3.02 | 2.46 | 1.56 |
| Water..... | 7.23 | 6.04 | 8.21 |
| | 100.00 | 100.00 | 100.00 |

I. Beechwood charcoal from piles. II. Hard charcoal from wood-vinegar-works. III. Light charcoal from wood-gas-works.

The proportion of hydrogen and oxygen existing in *dry* charcoal will depend upon the temperature at which carbonization has been effected: the higher the temperature the greater will be the proportion of carbon in charcoal.

Violette has analysed charcoal prepared from the same wood at gradually increasing temperatures, from that at which carbonization commences to that at which platinum melts. His most important results are contained in the following table :¹—

TABLE SHOWING THE PERCENTAGE COMPOSITION OF CHARCOAL PREPARED AT DIFFERENT TEMPERATURES FROM WOOD PREVIOUSLY DRIED AT 150° C.

| No. | Temperature in Centigrade Degrees at which Carbonization was effected. | Composition of Charcoal produced. | | | | Observations.* |
|-------|--|-----------------------------------|-----------|-----------------------------|------|---|
| | | Carbon. | Hydrogen. | Oxygen, Nitrogen, and Loss. | Ash. | |
| I. | 150° | 47.51 | 6.12 | 46.29 | 0.08 | The products obtained at these temperatures cannot properly be termed charcoal. |
| II. | 200° | 51.82 | 3.99 | 43.97 | 0.22 | |
| III. | 270° | 70.45 | 4.64 | 24.06 | 0.85 | |
| IV. | 350° | 76.64 | 4.14 | 18.61 | 0.61 | |
| + V. | 432° | 81.64 | 1.96 | 15.24 | 1.16 | Melting-point of antimony. do. silver. do. copper. do. gold. do. steel. do. iron. do. platinum. |
| VI. | 1023° | 83.29 | 2.30 | 14.13 | 1.60 | |
| VII. | 1100° | 83.29 | 1.70 | 13.79 | 1.22 | |
| VIII. | 1250° | 88.14 | 1.41 | 9.25 | 1.20 | |
| IX. | 1300° | 90.81 | 1.58 | 6.46 | 1.15 | |
| X. | 1500° | 94.57 | 0.74 | 4.03 | 0.66 | |
| XI. | Beyond 1500° | 96.51 | 0.62 | 0.93 | 1.94 | |

* The Author does not accept as correct all the melting-points given in this column.

⁹ Wagner's Jahresbericht, 1855, i. 457.

¹ Ann. de Chim. et de Phys. s. 3, 1851, xxxii. 322.

The wood operated on was that of black alder or alder buckthorn (*Rhamnus Frangula*, L.), which furnishes a charcoal suitable for gun-powder.

III. was what the French term *très-roux*, from its yellowish-red or rusty colour; it was beginning to be pulverizable, and was well suited for the manufacture of sporting-powder. Such charcoal will in the sequel be termed *brown charcoal*. IV. was black charcoal like that of all the succeeding numbers. The results of V. and VI. are somewhat discordant; but it must be difficult, if not impracticable, to insure perfectly harmonious results in experiments of this kind.

The following table will serve as a companion to the last, and is interesting as showing the proportions of carbon and other matter expelled during carbonization at different temperatures:²—

TABLE SHOWING THE NATURE AND PROPORTIONS OF THE FIXED AND VOLATILE MATTER PRODUCED BY THE CARBONIZATION OF WOOD (PREVIOUSLY DRIED AT 150° C.) AT DIFFERENT TEMPERATURES.

| No. | Temperature in Centigrade Degrees at which Carbonization was effected. | Products of the Decomposition of 100 parts by weight of Wood by Carbonization at different Temperatures. | | | | | Sum of the Numbers in each Horizontal Line. |
|-------|--|--|-----------------------------|------|--|-----------------------------|---|
| | | Composition of the Solid Matter or Charcoal. | | | Composition of the Matter volatilized. | | |
| | | Carbon. | Gaseous Elements (H, O, N). | Ash. | Carbon. | Gaseous Elements (H, O, N). | |
| I. | 150° | 47.51 | 52.41 | 0.08 | .. | .. | 100.00 |
| II. | 200° | 39.95 | 36.97 | 0.18 | 7.66 | 15.34 | 100.00 |
| III. | 270° | 26.17 | 10.65 | 0.32 | 21.34 | 41.52 | 100.00 |
| IV. | 350° | 22.73 | 6.75 | 0.18 | 24.78 | 45.56 | 100.00 |
| V. | 432° | 15.40 | 3.25 | 0.22 | 32.11 | 49.02 | 100.00 |
| VI. | 1023° | 15.37 | 3.12 | 0.30 | 32.14 | 49.11 | 100.04 |
| VII. | 1100° | 15.32 | 2.86 | 0.22 | 32.19 | 49.41 | 100.00 |
| VIII. | 1250° | 15.81 | 1.91 | 0.22 | 31.70 | 50.36 | 100.00 |
| IX. | 1300° | 15.86 | 1.40 | 0.20 | 31.65 | 50.89 | 100.00 |
| X. | 1500° | 16.37 | 0.83 | 0.11 | 31.14 | 51.55 | 100.00 |
| XI. | Beyond 1500° | 14.48 | 0.23 | 0.29 | 33.03 | 51.97 | 100.00 |

The wood experimented upon was that of black alder or alder buckthorn (*Rhamnus Frangula*, L.); the horizontal line No. I. gives its composition, when dried at 150° C. In order to show the use of this table, suppose, for the sake of example, that a question should be asked concerning the effect of carbonizing wood at 432° C. The answer will be found in the horizontal line No. V., and is as follows:—The weight of the charcoal is $15.40 + 3.25 + 0.22 = 18.87$ per cent. of the dry wood; and the charcoal consists of 15.40 of carbon, 3.25 of oxygen, hydrogen, and nitrogen, and 0.22 of ash. In producing that weight of charcoal from 100 parts by weight of dry wood, the matter

² Violette, Ann. de Chim. et de Phys. s. 3, 1851, xxxii. 325.

volatilized is $32.11 + 49.02 = 81.13$ per cent., and consists of 32.11 of carbon, and 49.02 of the gaseous elements, hydrogen, oxygen, and nitrogen.

Violette experimented upon the carbonization of wood in hermetically closed vessels, and for this purpose made use of thick glass tubes, each of which was just large enough to receive a single stick of alder buckthorn, weighing 1 gramme after having been dried at 150°C . After the introduction of the wood, the open ends of the tubes were drawn out fine and sealed before the blowpipe; and then the tubes were enclosed in metal cases and exposed during three hours to a current of steam superheated to from 160°C . to 340°C . At the higher temperatures, frequent explosions occurred, and when, after the completion of the carbonization, the end of a tube was broken off, even at its finest part, violent detonation followed, which shattered the tube to pieces, broke and projected the charcoal in particles, and dispersed the liquid product of distillation. But this difficulty was overcome by placing the drawn-out end in the flame of a spirit lamp, when it softened, gradually yielded, and finally opened in an imperceptible fissure, from which the gas escaped with a hissing sound, the charcoal and internal liquid remaining intact, so that they might be easily taken out and weighed. It was found that the proportion by weight of carbonaceous residue in these experiments differed greatly from that obtained at the same temperature in vessels, from which the volatile products could freely escape, as will be seen in the following table:—

TABLE SHOWING THE YIELD OF WOOD-CHARCOAL BY CARBONIZATION WHEN THE VOLATILE PRODUCTS ARE NOT ALLOWED TO ESCAPE, BUT ARE RETAINED UNDER PRESSURE.

| No. | Temperature of Carbonization in Centigrade Degrees. | Yield by Weight of Charcoal per cent. of the dry Wood. | |
|-------|---|--|---|
| | | By Carbonization, not under Pressure. | By Carbonization, under Pressure, in hermetically closed Vessels. |
| I. | 160° | 98.00 | 97.4 |
| II. | 180° | 88.59 | 93.0 |
| III. | 200° | 77.10 | 87.7 |
| IV. | 220° | 67.50 | 86.4 |
| V. | 240° | 50.79 | 83.0 |
| VI. | 260° | 40.23 | 82.5 |
| VII. | 280° | 36.16 | 83.8 |
| VIII. | 320° | 31.77 | 78.7 |
| IX. | 340° | 29.66 | 79.1 |

In the next table is given the composition of the charcoal produced under pressure at the temperatures stated in the last table:—

TABLE SHOWING THE COMPOSITION OF WOOD-CHARCOAL MADE AT DIFFERENT TEMPERATURES UNDER PRESSURE.

| No. | Temperature of Carbonisation in Centigrade Degrees. | Composition per Cent. | | | |
|-------|---|-----------------------|-----------|-----------------------------|------|
| | | Carbon. | Hydrogen. | Oxygen, Nitrogen, and Loss. | Ash. |
| I. | 160° | 49.02 | 5.30 | 45.53 | 0.15 |
| II. | 180° | 56.52 | 6.19 | 37.09 | 0.20 |
| III. | 200° | 61.04 | 5.25 | 33.42 | 0.29 |
| IV. | 220° | 66.42 | 4.98 | 28.01 | 0.59 |
| V. | 240° | 67.13 | 5.17 | 25.93 | 1.77 |
| VI. | 260° | 67.62 | 5.10 | 25.20 | 2.03 |
| VII. | 280° | 64.60 | 5.42 | 26.78 | 3.20 |
| VIII. | 320° | 65.62 | 4.76 | 25.55 | 4.07 |
| IX. | 340° | 77.07 | 4.71 | 14.88 | 3.84 |

At the temperature of 180° C. under pressure, the product was very brown (*très-roux*), very friable, and in physical properties exactly like the brown (*roux*) charcoal which is produced *not* under pressure at 280° C.; but in chemical composition it differed greatly from the latter, of which the percentage composition was found to be—carbon, 72.64—hydrogen, 4.71—oxygen, nitrogen, and loss, 22.08—ash, 0.57. At the temperature of 300° C. and beyond, wood, according to Violette, under the conditions of his experiments, fuses, loses all organic structure, and adheres strongly to the tube. When cold, it is lustrous, cavernous, hard, brittle, and exactly resembles caking coal (*houille grasse*).

Sir James Hall, at the beginning of this century, heated fir sawdust under compression, and produced a substance which appeared to him to resemble coal. He states that the wood entered into fusion, and yet retained "the form of its fibres;" but surely, if fusion, properly so called, had taken place, the structure of the wood must have been entirely destroyed.¹

One of the most striking statements in the last table is the large proportion of ash in the charcoal, as compared with that in charcoal not made under pressure (see the preceding tables, p. 354). Violette directs particular attention to this point, maintaining that his observations upon it are quite correct; and he infers therefrom, that in ordinary methods of carbonization the matters which are volatilized carry off about 3 per cent. of such mineral substances as lime, soda, and potash, either mechanically, or in a state of combination with hydrogen (?) analogous to such known compounds as potassiuretted,

¹ Account of a Series of Experiments, showing the Effects of Compression in modifying the Action of Heat. By Sir James Hall, Bart., F.R.S. Edin. Read in the Royal Society of Edinburgh, June 3, 1803; pp. 82 and 85. Separately printed. I have a specimen of the substance which

Hall himself obtained. It was in a small collection of various products got by Hall in his experiments on heating under compression, which belonged to Faraday, and was presented to me by his widow shortly after his death.

arseniuretted and carburetted hydrogen. The accuracy of this explanation may be fairly questioned, and, assuming the data to be correct, it would be necessary to enquire whether the increase in question might not have been derived from the substance of the glass, which at temperatures ranging from 260° C. to 340° C. was found to be much acted upon by the liquid products of the distillation of the wood. After carbonization, the state of the charcoal could be seen through the tubes, each containing about 1 cubic centimetre of liquid, which was occasionally limpid and of a slight yellow tint, but oftener white, milky, and opaque. Violette remarks that the glass, which always continued transparent after carbonization, became opaque on being gently heated in a flame, and coated internally with an adherent white, enamel-like layer, supposed to be silica, resulting from the decomposition of the glass, which had been profoundly altered.

PROPORTION OF ASH YIELDED BY WOOD-CHARCOAL.

The proportion of ash yielded by charcoal will obviously vary with the nature of the wood from which the charcoal has been produced. It has been stated to be on the average about 3 per cent.;¹ but on reference to the tables of the composition of various kinds of wood, it will be seen that the proportion of 3 per cent. of ash may be greatly exceeded. Knowing the percentage of ash in any given wood, and estimating the average yield of charcoal at 23 per cent.² by weight, the proportion of ash in the charcoal may be calculated.

SPECIFIC HEAT OF WOOD-CHARCOAL.

The specific heat of ordinary wood-charcoal, according to Regnault, is 0.2411.

SPECIFIC GRAVITY AND WEIGHT OF WOOD-CHARCOAL.

The specific gravity of charcoal varies with the nature of the wood from which it is made, with the age of the wood, with the state of the wood as to dryness, and with the mode of carbonization. New and accurate determinations of the specific gravity of charcoal from different kinds of wood, with statements as to the age of the wood, mode of carbonization, etc., are needed. It is stated by Hassenfratz, that the specific gravity of charcoal, *inclusive* of its pores, ranges from 0.203 in birchwood charcoal to 0.106 in limewood charcoal, that of oak being 0.155 or intermediate; and by Violette, that, *exclusive* of its pores—i.e., after replacement of the air contained in the pores by water—it ranges from 1.402 to 2.002, according as carbonization has

¹ Richard, *Études sur l'Art d'extraire immédiatement le Fer de ses Minerais*, p. 48.

² Scheerer, *Lehrbuch der Metallurgie*, i. 254.

been conducted at temperatures ranging from 150° C. to 1500° C.⁴ A knowledge of the specific gravity of charcoal inclusive of pores is not of much practical value, because the amount of water absorbed may vary considerably according to circumstances; and because, owing to difference of size and form of the pieces of charcoal, there may be likewise great variation in the proportion of interstitial space.

It has been accurately determined at Prussian ironworks that 1 cubic foot of charcoal from Scotch fir weighs from 10·3 to 10·9 pounds avoirdupois; and that 1 cubic foot of oak or beech charcoal weighs from 13·2 to 14·1 pounds.⁵ According to separate computations of several observers, the average weight of a cubic metre of the charcoal, used in the old Catalan forges of the Pyrenees, was 222 kilogrammes; but in such determinations, considerable variation in weight may result from difference in the manner of filling the measure.⁶ François had the weight of a cubic metre of charcoal from different kinds of wood in the Ariège, French Pyrenees, determined under his own inspection, and the results are given in the following table:⁷—

TABLE SHOWING THE WEIGHT OF A CUBIC METRE OF CHARCOAL FROM DIFFERENT KINDS OF WOOD IN THE ARIÈGE.

| | Kilogrammes per Cubic Metre. |
|--|---------------------------------|
| Oak, black, 25 years old | 235 |
| Beech, coppice-wood, cut after an interval of 19 years..... | 229 |
| Beech, large, and cut into billets..... | 218 |
| Chestnut, young..... | 192 |
| Scotch fir? (<i>Pin</i>), branch-wood | 173 |
| Silver fir mixed (<i>Sapin mêlé</i>), large wood and branches..... | 152 |
| Alder | 141 |

In the department of Ardennes, in France, the weight of a cubic metre of charcoal produced in circular piles from a mixture of the hard wood of beech, oak and hornbeam, and from a mixture of the soft wood of poplar and willow, is stated to be 220 and 180 kilogrammes, respectively.⁸

COMBUSTIBILITY OF WOOD-CHARCOAL.

Violette states that charcoal made at 260° C. burns most easily; and that that made between 1000° and 1500° C. cannot even be ignited like ordinary charcoal. Charcoal made at a constant temperature of 300° C. takes fire in air when heated to between 360° and 380° C., according to the nature of the wood from which it has been derived; charcoal from light woods, *cæteris paribus*, igniting most easily. Charcoal made between 260° and 280° C., ignites between 340° and 360° C.; that

⁴ Ann. de Chim. et de Phys. s. 3, 1853, xxxix. 340.

⁵ Handwörterbuch der Chemie, iv. 443.

⁶ Richard, Études sur l'Art d'extraire immédiatement le Fer de ses Minerais, p. 5.

⁷ Recherches sur le Gisement et le Traitement direct des Minerais de Fer, 1843, p. 177.

⁸ Sauvage, Ann. des Mines, s. 3, 1837, xi. 532.

made between 290° and 350° C., ignites between 360° and 370° C.; that made at 432° C. ignites at about 400° C.; that made between 1000° and 1500° C., ignites between 600° and 800° C.; and that made at the melting-point of platinum only ignites at about 1250° C. Violette, it will be perceived, applies the term charcoal to every imperfectly carbonized, indeed scarcely more than dried, wood.⁹ Charcoal, when stacked soon after its preparation, has been known to ignite spontaneously;¹ probably from the heat developed by the condensation of atmospheric air.

ABSORPTION OF GASES BY WOOD-CHARCOAL.

Owing to its highly porous structure, charcoal has the power of absorbing and condensing gases in considerable quantity. Théodore de Saussure experimented upon this subject early in the present century, and his results have been generally quoted in chemical books, and until recently accepted as correct. He operated upon boxwood charcoal, which had been heated to strong redness and then extinguished by immersion in mercury. Charcoal thus treated was put into different gases and left therein at 12° C., under a barometric pressure of 738 millimetres (= 29·055 inches) of mercury, until absorption ceased, which, except in the case of oxygen, occurred after the lapse of from 24 to 36 hours. The absorption of oxygen was found to go on continually, though decreasingly, with the formation of carbonic acid, which was retained in the pores of the charcoal; but in the course of an entire year it did not amount to more than about 14 times the volume of the charcoal.² In the following table is shown the volume of various gases which, according to De Saussure, a given volume of freshly-made boxwood charcoal is capable of absorbing:—

TABLE SHOWING THE NUMBER OF VOLUMES OF VARIOUS GASES ABSORBED BY ONE VOLUME OF BOXWOOD CHARCOAL.

| | | | |
|-----------------------------|----|----------------------|------|
| Ammonia | 90 | Carbonic acid | 35 |
| Hydrochloric acid | 85 | Carbonic oxide | 9·42 |
| Sulphurous acid | 65 | Oxygen | 9·25 |
| Sulphuretted hydrogen | 55 | Nitrogen | 7·6 |
| Olefiant-gas | 35 | Hydrogen | 1·75 |

From these data it would appear that the volume of gas absorbed is great in proportion to the condensability of the gas by pressure.

An investigation has been made by Blumtritt in the laboratory of Professor Reichardt, of Jena, concerning the nature and quantity of

⁹ Ann. de Chim. et de Phys. s. 3, 1853, xxxix. 340. Violette's deuxième Mémoire sur les Charbons de Bois, idem, pp. 291-342.

¹ Reichard, Études sur l'Art d'extraire

immédiatement le Fer de ses Minerais, p. 50.

² Berzelius, Traité de Chimie, 1845, i. 271.

the gas existing in various solid substances, of which one was wood-charcoal.³ The gas was evolved by heating the substance under mercury to 140° C. in a paraffin bath, in an apparatus contrived by Reichardt. In the following table are given Blumtritt's results obtained in the case of charcoal :—

TABLE SHOWING THE NATURE AND QUANTITY OF THE GASES EXISTING IN WOOD-CHARCOAL.

| Number. | Kind of Charcoal. | Number of Cubic Centimetres of Gas yielded by 100 Grammes of Charcoal. | Number of Volumes of Gas yielded by 100 Volumes of Charcoal. | Percentage Composition, by volume, of the Gases evolved. | | | |
|---------|---|--|--|--|---------|----------------|-----------------|
| | | | | Nitrogen. | Oxygen. | Carbonic Acid. | Carbonic Oxide. |
| I. | Common wood-charcoal | 164.21 | .. | 100.00 | .. | .. | .. |
| II. | The same, after having been moistened and dried | 140.11 | 59.0 | 85.60 | 2.12 | 9.15 | 3.13 |
| III. | Charcoal from <i>Populus pyramidalis</i> | 466.95 | 198.2 | 83.50 | .. | 16.50 | .. |
| IV. | Ditto ash (<i>Pratinus excoelior</i>) | 473.00 | 159.0 | 76.03 | 14.87 | 9.10 | .. |
| V. | Ditto alder (<i>Alnus glutinosa</i>) | 287.07 | 109.9 | 88.27 | .. | 5.42 | 6.31 |
| VI. | Ditto ditto ditto in pieces | 117.67 | .. | 78.88 | .. | 21.12 | .. |

The volume of gas is estimated dry at 760 millimetres pressure, and at 0° C.

I. The charcoal was from coniferous wood, chiefly silver fir, such as is sold for fuel. Shortly before the experiment it was finely triturated. It is remarkable that the gas consisted wholly of nitrogen.

II. The difference in composition between the gas in this case and that in the case of I. is noteworthy. Oxidation of the charcoal, with the formation both of carbonic acid and carbonic oxide, seems to have been promoted by the presence of moisture.

III. The charcoal had been quite freshly made in a covered crucible and finely triturated. It was found to contain 0.042 per cent. of ammonia, and this was the only instance in which that gas was detected in charcoal.

IV. and V. The charcoal had been made in a covered crucible and finely triturated soon afterwards.

VI. It will be seen that charcoal, in pieces, made from alder contained less than half of the volume of gas existing in the same kind of charcoal in the state of powder, yet an actually greater volume of carbonic acid.

Nitric acid was carefully sought for by Blumtritt in his experiments on wood-charcoal, but not detected in a single instance.

Blumtritt's results differ widely, so far as they relate to the volume of gases absorbed by charcoal, from those of De Saussure; and his method of experimenting also differed much from that of the Swiss chemist, who noted the diminution in volume which the gases suffered

³ Ueber die Gase, welche durch Erhitzen von trockenen Körpern entfernt werden können; von Dr. E. Blumtritt. Erdmann's Journal für praktische Chemie, 1866, xviii. 418-458. Also in the same volume, Ueber die Bestimmung der von festen Körpern absorbirten Gasarten; von Prof. Dr. E. Reichardt in Jena.

by prolonged contact with charcoal, whilst Blumtritt endeavoured to ascertain the degree of absorption by measuring the gas evolved at 140° C.

ABSORPTION OF AQUEOUS VAPOUR BY WOOD-CHARCOAL.

Ordinary charcoal readily absorbs from 10 to 12 per cent. of its weight of aqueous vapour, and may even absorb as much as 20 per cent. The power of charcoal to absorb moisture is much affected by the temperature at which it was produced; the lower the temperature, the greater the power, and the more rapid the absorption. Thus charcoal prepared at 150°, 250°, 350°, 430°, and 1500° C. absorbs 21, 7, 6, 4, and 2 per cent., respectively, of moisture by exposure to a moist atmosphere. In general, according to François, light varieties of charcoal absorb more moisture than dense (*forts*) ones, and those produced by rapid charring more than those produced by charring with moderation.⁴ Charcoal in powder absorbs about twice as much moisture as the same charcoal in pieces.⁵ The proportion of water which it retains will necessarily vary with the degree of humidity of the atmosphere. Commercial charcoal may be estimated to contain not less than 9, and generally about 12, per cent. of moisture; and when heated to whiteness, it loses from 14 to 15 per cent. of combustible gases and aqueous vapour.

GASES EVOLVED FROM WOOD-CHARCOAL AT HIGH TEMPERATURES.

Commercial charcoal, even when well burnt, contains a sensible amount of hydrogen and oxygen, as Bunsen and Playfair have demonstrated.⁶ They analysed the gases evolved from various specimens of charcoal strongly heated in close vessels, and found their composition by volume to be as follows:—

TABLE SHOWING THE COMPOSITION, PER CENT., BY VOLUME OF THE GASES EVOLVED FROM WOOD-CHARCOAL WHEN STRONGLY HEATED.

| | I. | II. | III. | IV. |
|--------------------------|---------------|---------------|---------------|---------------|
| Carbonic acid | 23·65 | 15·96 | 19·58 | 35·36 |
| Carbonic oxide | 15·96 | 13·62 | 20·57 | 14·41 |
| Hydrogen | 49·39 | 50·10 | 39·10 | 29·45 |
| Carburetted hydrogen ... | 11·00 | 20·32 | 20·75 | 20·78 |
| | <u>100·00</u> | <u>100·00</u> | <u>100·00</u> | <u>100·00</u> |

I. Very-well-burnt beechwood charcoal.

II. Well-burnt firwood charcoal.

III. Well-burnt oak charcoal. 0·65 gramme yielded 70 cubic

⁴ Traitement direct des Minerais de Fer, p. 178.

⁵ Violette, Ann. de Chim. et de Phys.

s. 3, 1853, xxix. 339.

⁶ British Assoc. Rep. 1845, p. 145.

centimetres of gas, at 0° C. and 760 millimetres pressure; and a residue weighing 0.47 grm.

IV. Imperfectly-burnt beechwood charcoal, pulverulent and of a blackish-brown colour. 0.733 grm. yielded 250 cubic centimetres of gas, at 0° C. and 760 millimetres pressure; and a residue weighing 0.443 grm.

For the sake of comparison are here inserted the following results which Pettenkofer obtained by carbonizing wood in boiling mercury; the charcoal so formed is described as black and bright (*schwarze glänzende Kohle*): the *permanent gases* produced were composed as follows, exclusive of about 5 per cent. of atmospheric air:—

COMPOSITION, PER CENT., BY VOLUME OF THE PERMANENT GASES EVOLVED BY CARBONIZING WOOD AT THE TEMPERATURE OF BOILING MERCURY.

| | |
|----------------------|-------|
| Carbonic acid | 54.5 |
| Carbonic oxide | 33.8 |
| Marsh-gas | 6.6 |
| | <hr/> |
| | 94.9 |
| | <hr/> |

If the *volatile products* from the carbonization (under the usual conditions) of wood be subjected to a considerably higher degree of heat, a large quantity of olefiant-gas is generated; and hence the successful application of the gases, thereby produced, to the purpose of illumination. Their composition has been found to be as follows:—

COMPOSITION, PER CENT., BY VOLUME OF THE GASES PRODUCED BY EXPOSING THE VOLATILE PRODUCTS OF THE CARBONIZATION OF WOOD TO A VERY HIGH TEMPERATURE.

| | Per cent. |
|----------------------|-----------|
| Carbonic acid | 18 to 25 |
| Carbonic oxide | 40 to 50 |
| Hydrogen | 14 to 17 |
| Marsh-gas | 8 to 12 |
| Olefiant-gas..... | 6 to 7 |

The volatile products, condensable as well as permanently gaseous, evolved from different kinds of wood, such as beech and fir, have essentially the same composition.⁷

Ebelmen has determined the composition of the gases evolved from the charcoal of poplar and young oak, obtained by charring in piles.⁸ Both were dried between 140° and 150° C. The oak charcoal had been long exposed to the air. The poplar charcoal lost 5.2 per cent., and the oak charcoal 6 per cent. in weight by desiccation at the temperature above stated. The loss by exposure to a white-heat in a

⁷ Wagner's Jahresbericht, 1857, iii. 473 of seq. I presume the composition of the gases above quoted is by volume and not by weight; this, however, is not dis-

tinctly stated.

⁸ Recueil des Travaux scientifiques, ii. 228.

platinum crucible was also ascertained, and the results are given in the following table:—

TABLE SHOWING THE AMOUNT AND COMPOSITION OF THE MATTER EVOLVED BY SUBJECTING DRY WOOD-CHARCOAL TO A WHITE HEAT.

| | | Poplar. | Oak. |
|---|----------------|---------|-------|
| Number of parts, by weight, of matter evolved at a white heat from 100 parts by weight of dry charcoal. | | 17·07 | 13·06 |
| Composition per cent. of the matter so evolved. | Carbon | 30·1 | 28·7 |
| | Hydrogen | 18·7 | 21·6 |
| | Oxygen | 51·2 | 49·7 |
| Total | | 100·0 | 100·0 |

ACTION OF STEAM ON INCANDESCENT CHARCOAL.

When steam is passed over red-hot charcoal, hydrogen, marsh-gas in small proportion, carbonic oxide, and carbonic acid are produced. Langlois has investigated this subject, and in his experiments the charcoal was kept at a red-heat in a porcelain tube, one end of which communicated with a glass retort containing water for the generation of steam, and the other with an inverted glass jar filled with mercury. Much of the gas formed at first was allowed to escape, after which seven jars of it were collected and separately analysed. The carbonic acid was absorbed by caustic potash, and the carbonic oxide by an ammoniacal solution of dichloride of copper, $\text{Cu}^2\text{Cl} [\text{Cu}^2\text{Cl}^2]$. The results are shown in the following table:^s—

TABLE SHOWING THE COMPOSITION, PER CENT., BY VOLUME OF THE GASES FORMED BY PASSING STEAM OVER INCANDESCENT WOOD-CHARCOAL, AND COLLECTED IN DIFFERENT RECEIVERS.

| Gas. | 1st Jar. | 2nd Jar. | 3rd Jar. | 4th Jar. | 5th Jar. | 6th Jar. | 7th Jar. |
|-------------------|----------|----------|----------|----------|----------|----------|----------|
| Hydrogen | 59·11 | 58·64 | 60·55 | 60·48 | 60·18 | 60·37 | 59·86 |
| Carbonic oxide... | 21·89 | 26·07 | 20·00 | 20·83 | 21·42 | 19·31 | 20·76 |
| Carbonic acid ... | 19·00 | 15·29 | 19·45 | 18·69 | 18·40 | 20·82 | 19·38 |
| Total | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 |

From these results, it appears that the gases had nearly always the same composition at every period of their production. The proportion of carbonic acid, compared with that of carbonic oxide, is much larger than what is usually observed. As this might be due to too low a temperature, the experiment was repeated at a sustained

^s Ann. de Chim. et de Phys. s. 3, 1857, li. 322.

red-white (*rouge-blanc*) heat. The composition of the gases thus formed was ascertained by the method of analysis above mentioned, as well as by explosion with oxygen in a eudiometer, and was found to be as follows:—

COMPOSITION, PER CENT., BY VOLUME OF THE GASES FORMED BY PASSING STEAM OVER WOOD-CHARCOAL AT A RED-WHITE HEAT.

| | I. By the 1st method of analysis. | II. By the 2nd method of analysis. |
|----------------------|---|--|
| Hydrogen | 52·64 | 49·62 |
| Marsh-gas | — | 2·17 |
| Carbonic oxide | 41·36 | 42·21 |
| Carbonic acid..... | 6·00 | 6·00 |
| | <hr/> 100·00 | <hr/> 100·00 |
| Oxygen consumed..... | | 50·25 |

Hence, it appears that at the higher temperature the proportion of carbonic oxide formed is much greater, and that that of the carbonic acid is proportionately smaller.

Another experiment was made in order to ascertain whether the composition of the gases is influenced by the quantity of charcoal exposed to the action of steam, and for this purpose a single piece of charcoal was operated upon, of which the dimensions in every direction scarcely exceeded 2 centimetres, and the result was found to be as follows by the eudiometrical method of analysis:—

COMPOSITION, PER CENT., BY VOLUME OF THE GASES FORMED BY PASSING STEAM OVER A SINGLE VERY SMALL PIECE OF WOOD-CHARCOAL, AT A RED-WHITE HEAT.

| | |
|-----------------------|--------------|
| Hydrogen..... | 54·25 |
| Marsh-gas | 1·74 |
| Carbonic oxide | 35·37 |
| Carbonic acid | 8·64 |
| | <hr/> 100·00 |
| Oxygen consumed | 48·29 |

This experiment, which was repeated several times with the same result, would tend to show that, supposing the carbon, which is oxidized, to be first converted into carbonic acid, the latter is for the most part instantaneously reduced to carbonic oxide, and that a considerable mass of charcoal is not, at this temperature, required to effect such reduction.

VARIOUS MODES OF CHARCOAL-BURNING.

Charcoal-burning is effected in the open air in piles or stacks (in the singular number, *meule* in French and *Meiler* in German) provided with a yielding cover; in pits; in closed chambers of brick or stone; and in iron retorts heated externally like common gas-retorts. The latter method is practised by the manufacturers of pyroligneous acid and gunpowder, and is not specially within the province of the metallurgist.

CHARRING IN CIRCULAR PILES.

Dry level ground, well sheltered from the wind, and if possible near a water-supply, should be chosen for the site. The bed on which the pile rests should have a slight inclination upwards, from the circumference to the centre. In the centre three stakes, *a*, fig. 39, are driven in vertically about a foot equidistant from each other, and are prevented from yielding to pressure from without by means of pieces of wood placed crosswise from stake to stake, or by suspending a single block of wood between them. Pieces or

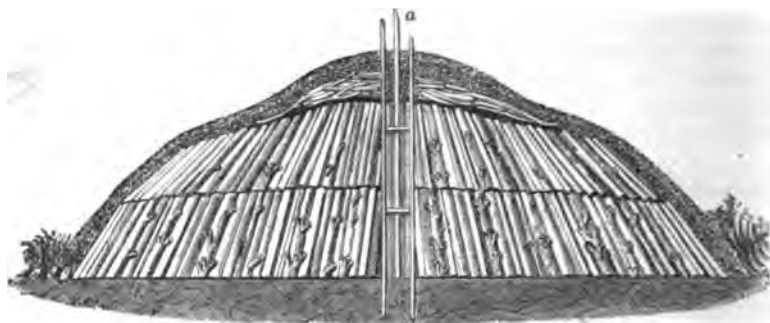


Fig. 39. Vertical section through the centre of a pile. At the foot on the left the cover is shown resting on stones, and on the right it is shown resting on branches supported by forked sticks. Copied from No. 301 of Karsten's Atlas.

logs of wood of equal length are piled concentrically around the stakes, placing those nearest the centre almost vertical, and giving the surrounding pieces a slight but gradually increasing inclination. A second layer of wood, and in the case of very large piles even a third, may be stacked in a similar manner, one above another. The wood should be packed as close as possible; and all large interstices, due to irregularity of shape in the pieces, should be filled with the small wood of branches. The top of the pile is covered with a layer of the same kind of small wood, placed horizontally and radially, so that the whole pile may have the form of a truncated cone, rounded at its upper and smaller end. Close to and round the base of the pile, a row of forked sticks is driven into the ground, with the forked ends uppermost and about six inches out of the ground. The pile is then encircled with a band of branches, resting

in the forks of these sticks. This band supports the cover of the pile which has next to be applied. A row of stones or pieces of wood placed at intervals may be used instead of forked sticks. The surface of the pile is made more or less even by packing in here and there bits of wood or small branches. The whole pile above the band of branches, except the space between the tops of the three central stakes, is now covered with turf, placing the *grassy side inwards*; and if turf cannot be got, leaves or moss may be substituted. The turf is plastered over with a layer some inches thick of the soil which may be at hand, or, when procurable, with a mixture of the residual charcoal-dust, or *breeze*,⁹ of previous burnings and soil, moistened sufficiently with water. As a rule the cover should be most solid and thickest at the top of the pile, where it is longest and most exposed to the action of heat.

The pile is now ready for lighting. It is desirable that this should be done early in the morning, and during fine weather, because at first much attention is required on the part of the charcoal-burner; and because it is important that the pile should be well and regularly kindled, a condition which cannot be ensured in bad weather. The space within the three central stakes, or chimney, is filled with easily inflammable wood, which is then ignited, and the fire is kept up by a supply of fresh wood or charcoal, until the centre of the pile has become thoroughly kindled. Any sinkings-in which may occur at the top of the pile must be made good by taking off the cover from that part and putting in fresh wood. The chimney is afterwards well filled with small dry wood or charcoal, and effectually stopped by extending the turf and soil-covering over it, and pressing it well down. In this, the *first* or *sweating* stage of the process, much water condenses on the inner surface of the cover, and especially round the base or foot of the pile, which is left uncovered below the band of branches; during this stage, without proper attention on the part of the charcoal-burner, explosions are apt to occur, occasioned, it is said, by the ignition of explosive mixtures of atmospheric air and the inflammable gaseous products of carbonization. In support of this statement it is alleged that explosions never occur when much steam escapes from the cover, and that they very frequently occur when dry and resinous wood is used.¹ Karsten, however, attributes these explosions to the sudden escape of steam.

When the sweating stage is over, the covering of the pile is extended to the previously-uncovered zone round the base, and any hollows which may be found by probing with a pole are filled up. The cover in every part is made solid and impervious to air, and the pile is left to itself during three or four days, the heat existing in its centre

⁹ I use this word *breeze* to denote the small residual charcoal obtained in charcoal-burning, just as the coke-burner applies it to the small residual coke obtained in coke-burning. It is derived from the French word *braies*, which is applied to the residual charcoal obtained

in the heating of bakers' ovens. It is drawn out, extinguished with water, and sold under the name of *braies*.

¹ Wehrle, *Lehrbuch der Probier- und Hüttenkunde als Leitfaden für akademische Vorlesungen*, i. 309.

being sufficient to effect the carbonization of much of the surrounding wood. If left too long in this state, the fire would be extinguished, to prevent which holes or vents are made in the cover round the pile, on a level with the top of the bottom layer of wood (fig. 39). Thick yellowish-grey smoke at first escapes from these vents, but after a time it becomes bluish and nearly transparent. These vents are then stopped, and another row of them is made underneath, when the same change in the appearance of the smoke ensues. The character of the smoke indicates exactly the degree of carbonization in that part of the pile from which it issues. If necessary, after the stopping of the second row of vents, a third may be opened about nine inches or so below. These vents serve for the *escape* of the volatile products of the carbonization, and *not for the admission of air*, which enters chiefly by openings made round the base of the pile. When only bluish transparent smoke proceeds from the lowest vents, every part of the surface of the pile must be well covered and rendered as impervious to air as practicable.

The pile is now left at rest during a few days, after which the charcoal may be drawn out, beginning on one side, at the bottom, and from this point proceeding all round, care being taken to cover up the pile as the charcoal is withdrawn, and to quench the latter with water. If water cannot be had, the charcoal must be covered with the dust of previous burnings, or with dry soil. If the pile were left to itself, it would in time be perfectly extinguished; but experience, it is stated, has shown that the charcoal in that case would be less serviceable than such as has been rapidly extinguished—as, for example, by water.²

The position of the vents may be varied according to circumstances. The object of the charcoal-burner should be to conduct the combustion as uniformly as possible from the top towards the bottom, and from the centre towards the circumference of the pile. By making a vent in any part of the pile, he has the power of establishing a current of air through, and, consequently, of increasing the combustion in, that part. During the process of carbonization, wood usually decreases considerably in volume, so that the degree of regularity in the contraction of a pile during the progress of burning is a measure of the regularity with which the process has been conducted. The cover, being yielding, adapts itself to the gradually decreasing size of the pile.

The method of charcoal-burning just described is of ancient date, and continues to be extensively practised; and in respect to *yield* and *quality* of charcoal, it is not, when properly conducted, surpassed by any other. It has the advantage of not requiring any permanent construction, so that the wood may be burned on the spot where it is cut down, and thus the expense of carriage to a distance may be greatly diminished, as the wood weighs about five times as much as the charcoal produced. It may be modified in details according to local circumstances, and the traditional practice of the charcoal-burner.

² Karsten, *System der Metallurgie*, iii. 69.

The left-hand side of fig. 40 represents a vertical section of half a pile, similar to that shown in fig. 39, but with a different method of supporting the cover, namely, by boards placed horizontally round the pile, resting on wooden props, *a*. The right-hand side of fig. 40 is a vertical section of the half of another kind of pile described farther on.

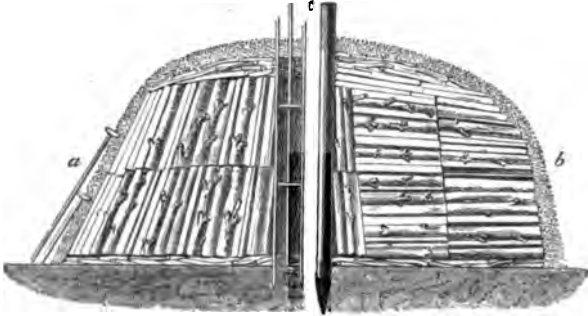


Fig. 40. Vertical sections through the centre of two kinds of circular piles; in one of which the wood is stacked vertically, and in the other horizontally. Copied from Nos. 300 and 302 of Karsten's Atlas.

FIRST MODIFICATION OF CHARRING IN CIRCULAR PILES.—The three central stakes may be replaced by one, *c*, fig. 40; but in this case it is necessary to construct a channel from the outside to the centre of the base of the pile, by means of which burning fuel may be introduced so as to ignite the wood at the bottom of the central stake, immediately around which easily combustible matter should be placed. For this purpose imperfectly charred wood from a previous charring may be used. When the pile is well kindled, the outer end of the channel must be

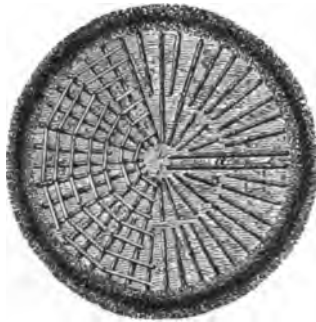


Fig. 41. Plan of a circular pile at Ruhpolding in Bavaria. Copied from plate 2 of Klein's Treatise.

closed. The channel may be made, either by leaving a space between the logs at the bottom, or by making a furrow in the bed of the pile. Pieces of wood may be placed upon the bed, radiating from the centre as in fig. 41, and the channel formed by two parallel pieces as at *a*; pieces of wood are next arranged concentrically, as shown in one-half of the

same figure, and so a firm foundation of wood is made for the pile. The channel may, however, be omitted, and a central stake fixed, extending upwards about one-third of the height of the pile, a hollow space being left above the stake for the purpose of igniting in the manner first described. The outer dark ring in fig. 41 represents charcoal-dust or *breeze* covering the bed of the pile.

Fig. 42 is a vertical section of a pile through the centre. Around the central stake, *b*, is packed easily inflammable wood, such as the



Fig. 42. Vertical section through the centre of a circular pile at Ruhpolding in Bavaria. Copied from plate 2 of Klein's Treatise.

imperfectly carbonized pieces termed *brands* from a previous charring. The lower part of the cover is supported by stakes, *c*: in the middle of each of these stakes is fixed, at right angles, a board, *d*. Resting upon the tops of the stakes, *c*, are boards, *e*, extending round the pile.



Fig. 43. Charcoal-burning at Ruhpolding in Bavaria.

These boards support the cover from *e* to *f*. The upper part of the pile is propped all round by poles, on the top of each of which is fixed a cross-piece, as shown at *f*, fig. 42, and in fig. 43, in which one is seen

lying in the foreground to the left. The pile is left uncovered round the zone, *g*, for some time after ignition.

Fig. 43 represents a pile of this kind, of which the height is 16 feet: the man on the plank is engaged in carrying up the breeze with which to complete the cover at the top; in the left foreground are various implements used by the charcoal-burner; the scene is Ruhpolding, in Bavaria, and the artist is Mr. Justyne, who, with the exception of the picturesque group of figures, has derived the materials of his drawing from the plates in the work of Klein.³

SECOND MODIFICATION OF CHARRING IN CIRCULAR PILES.—The wood is piled horizontally and radially in concentric rows. The spaces between the pieces will be wider towards the outside than the centre, and these must be well packed with small wood. By sawing the wood to suitable lengths, the pieces may be so piled as to form a series of steps round the outside of the pile, which will tend to prevent the cover from slipping off. By this means of supporting the cover, the pile may be made much steeper, a condition favourable to complete carbonization of the whole mass. The outer ends of the pieces upon which the cover rests are less cooled in steep piles than in flat ones.⁴

THIRD MODIFICATION OF CHARRING IN CIRCULAR PILES.—The pieces are piled at first vertically round the axis for some distance, and then horizontally as shown at *b* on the right-hand side of fig. 40. In this arrangement Karsten remarks that the hollow spaces are reduced to a minimum; and with pieces of equal length in the outer part of the pile steps are formed, as in the last case, by which the cover is firmly supported. It is especially necessary, in a pile of this kind, according to Karsten, to cover the bed with a layer of waste pieces of wood, in order that the charring may extend well to the bottom.

There has been much discussion whether it is most advantageous to stack the wood vertically or horizontally, and practical charcoal-burners are still far from unanimous on the subject. Experimental results have been advanced in favour of each method of stacking.

FOURTH MODIFICATION OF CHARRING IN CIRCULAR PILES.—A conical cavity, lined with brick, 1.33 metre (4 ft. 4½ in.) in diameter at the top, 0.5 metre (1 ft. 7¾ in.) at the bottom, and 0.5 metre (1 ft. 7¾ in.) deep, is made in the centre of the bed. Three rectangular brick flues, 0.12 metre (4¾ in.) on the side, proceed from the bottom of this cavity, and communicate with the external air beyond the base of the pile. The cavity is filled with small wood and imperfectly charred pieces, and then covered with sheet-iron. The construction generally resembles that which is described by Karsten, and represented in fig. 44. The diameter of the pile at the base is 9 metres (29 ft. 6½ in.); the wood is sawn in lengths of 0.67 metre (2 ft. 2½ in.), and piled vertically in

³ Ueber Verkohlung des Holzes in stehenden Meilern. Von Ferdinand Klein. Gotha, 1836.

⁴ Karsten, System der Metallurgie, iii. 55.

three layers one above another. In every part immediately over the cavity underneath, a thick layer of soil and small charcoal is put upon the first layer of wood, but in other respects the pile is made in the usual way, except that no central chimney space, or channel leading from the circumference to the centre of the bed, is left; care is taken to diminish the interstices as much as possible, and to stack each piece in a diametral plane passing through the axis of the pile. The fuel in the cavity is then ignited. The upper part of the pile is uncovered, and holes are opened round the base. When the fuel is well kindled, the three fires above mentioned are closed, the top is covered, and the process conducted as usual. From 28 to 35 cubic metres (987 to 1236 cubic feet) of wood may thus be carbonized in four or five days. At Audincourt, where this method is practised, it has been found better to operate upon this quantity of wood than upon 150 or 180 cubic metres (5298 to 6357 cubic feet) at a time, as was formerly done.⁵ The advantage claimed for this method is, that it does away with the central chimney space and the necessity of repeatedly charging that space with fresh wood during some time after lighting; but it is not adapted to charcoal-burning in forests, where the site of the pile is constantly changed; nor can it well be employed in very moist soils, on account of the difficulty of kindling the wood in the cavity. Another advantage in these small piles is that the charcoal-burner can more easily manage them than large ones.

FIFTH MODIFICATION OF CHARRING IN CIRCULAR PILES, WITH AN ARRANGEMENT FOR COLLECTING TAR AND PYROLIGNEOUS ACID.—This method, like the last, is only suitable when charring can be continuously and profitably conducted at one spot. Fig. 44 represents a vertical section through the centre of such a permanent bed of brick-



Fig. 44. Vertical section through the centre of a permanent bed of a circular pile. Copied from No. 297 of Karsten's Atlas.

work, *a*, which slopes *towards* the centre *downwards*, and not *downwards from* it as in the ordinary pile. In the centre of the bed, there is a cylindrical cavity, from which proceeds a channel, *b*, to a reservoir, *c*, provided with a movable cover, *g*, such as a plate of iron; the cylindrical cavity is covered with a square plate of iron, *d*, of which the corners are rounded off. The tar and other liquid products condense and trickle down between the sides of the plate, *d*, and the brickwork, and flow into the reservoir, *c*. The wood is stacked up in the usual way. Care must be taken to prevent access of air through the channel, *b*.

⁵ Ebelmen, Recueil des Travaux scientifiques, ii. 106. Published in 1855.

CHARRING IN CIRCULAR PILES BY FIRING AT THE BOTTOM
(DROMART'S PROCESS).

A particular method of charring in circular piles by firing at the bottom, instead of at the top in the usual manner, has been proposed by Dromart, and is reported to have been carried into successful operation at Solferino, and at Léon, near Dax, both in the department of the Landes, in the South of France.⁶ In the mode of applying heat, it is similar to Echement's process, described at p. 410. It is recommended for adoption on the following grounds: a twofold greater yield than that of the old method; the production of charcoal more uniform in quality, and made at the temperature desired by the purchaser; the practicability of charring throughout the year; reduction in the cost of labour by about one-fourth, and completing the process in a third of the time required by the old method; and in the facility of obtaining labour, because skilled charcoal-burners are not needed. Inventors, it is well to bear in mind, are apt to be too enthusiastic in favour of their own projects, and not unfrequently both they and their friends have suffered heavily in consequence.

The form and construction of the pile are shown in the annexed woodcuts, figs. 45 and 46. It is 5·25 metres in diameter at the base, and 4·5 metres high from the centre. On the ground, forming the bed of the pile, rests a ring of T-iron, *a*, called the bed-ring, to which are attached by means of hooks or cramps at equal distances apart sixteen wrought-

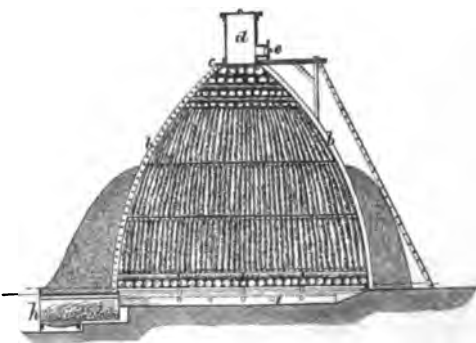


Fig. 45. Dromart's circular pile. Vertical section through the centre.

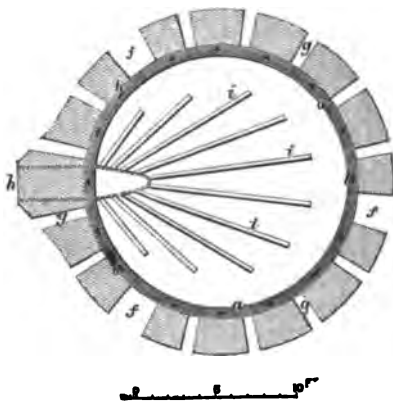


Fig. 46. Dromart's circular pile. Plan.

⁶ It is described in the *Annales du Génie civil*, 1867, p. 438, and a translation of it has been published in *Dingler's Polytechnisches Journal*, 1867, clxxxvi. 51-61.

iron T-shaped bearers, *b b b*, etc., having a hook at each end. These bearers converge towards the top, and there support a circular flat cast-iron ring, the chimney-ring, *c*. A chimney of wrought-iron, *d*, 1 metre in height and 0.70 metre in diameter, is screwed to that ring, and a little above the joint there is a branch pipe, *e*, inserted at right angles in the chimney. This pipe is provided with a movable cover, and serves for the introduction of fuel into the chimney which is there required in order to promote an upward draught through the pile during carbonization. The spaces between the bearers are closed hermetically with sheets of wrought-iron, which are tightly bolted to the ribs of the bearers. All these pieces of iron are smeared over with a mud of clay and water; their aggregate weight ought not to exceed 100 kilogrammes, with a view to their convenient removal from one spot to another; and for the same reason they should admit of being easily separated from each other and again united. In order to prevent the pile from being cooled by rain during carbonization, it should be entirely surrounded with an outer cover of thin sheets of wrought-iron, which only lie against the ribs of the bearers, so that an air-space of 4 centimetres wide is left between the outer and inner covers of the pile. Up to the height of about 2 metres from the base the pile is coated with turf and soil. In the foot of the pile, at equal distances apart from each other, are three openings, *f f f*, large enough for men to creep through in order to stack the wood and draw out the charcoal, and which are capable of being perfectly closed by fire-brick doors. There are also in the foot of the pile, at equal distances apart from each other, thirteen draught holes, *g g g*, etc., which communicate with the space between the two sheet-iron coverings of the pile, and by means of which cooling may be hastened when the charring is completed. In order to produce the heat required for carbonization, there is a fire-place, *h*, 1.50 metre long, below the level of the bottom of the pile, and extending only a short distance within the bed-ring towards the centre. It is composed of several pieces of cast-iron lined with fire-clay, only the outer half of it having a grate; and it is covered with fine sand in order to keep in the heat. It communicates with ten rectangular flues, *i i i*, etc., arranged like the ribs of a fan, on the bed of the pile, and closed at their distal ends, which are somewhat more than 0.5 metre from the inner edge of the bed-ring, and at equal spaces apart. These flues are formed of pipes, which fit into each other by socket joints: some of the pipes are made of fire-clay and the rest of cast-iron, the former being placed near the fire-place; and in their vertical sides are holes 4 centimetres in diameter, from which the hot gases of the fire-place escape and distribute their heat through the pile. By opening or closing these holes in a greater or less degree the course of carbonization may be suitably regulated.

In charging the pile, pieces of wood are placed horizontally and crosswise upon the pipes *i i i*, etc., and for this purpose round logs are preferred. Then, round a thick post firmly fixed in the centre, three or four layers of wood are stacked vertically in the usual manner, the

thickest pieces being placed towards the centre ; and the space between the highest of these layers and the chimney-ring is filled in with wood placed horizontally. After the charging is completed, the three doors, *fff*, are carefully closed, so that no air may pass through them during carbonization. Fire is made on the grate, and waste material of no commercial value, such as fir-cones, chips produced in felling the trees, and twigs, are used for fuel ; and it is kept up uninterruptedly with as much intensity as possible (?) until the end of the process. At first the draught is with difficulty established, particularly when the wood to be charred is either green or moist ; and, consequently, a little fire is made and maintained in the branch pipe, *e*, until the necessary draught is produced, which will occur in the course of one or two hours according to the moistness of the wood. After 10 hours' firing, the temperature of the pile will have risen to 100° C., when a considerable quantity of steam will escape from the chimney, and continue to do so until the temperature of the mass of wood has risen to 150° C., which will be found to be the case after 10 hours' additional firing. At this temperature the escaping vapour is darker and redder than previously, owing to its being charged with various volatile products ; and it will continue to darken in colour in proportion as the distillation of tar goes on, which begins at 200° C., and does not altogether cease until the end of the operation. At 330° C. less and lighter-coloured smoke is evolved, and the charring is then completed. When more highly burnt charcoal is desired, the temperature may be raised to 420° C., and this will be attained after further firing during 1½ or 2 hours. The former or ordinary kind of charcoal is said to be best for high blast-furnaces, and the latter for household use. The temperature is determined by thrusting into the pile a pipe containing a small bit of lead, zinc, or other metal or metallic alloy of known melting-point.

After the charring is finished, the fire-place is covered over with earth, or closed by means of a door plastered over with clay, so that no air may find its way from it into the pile. The chimney, however, is not stopped up until all the volatile products have been driven off, which happens in about 6 or 7 hours after the closing of the fire-place. Quick cooling of the pile is effected by opening the 13 draught-holes, *ggg*, etc., at the bottom, which during carbonization are kept stopped up with earth and turf. Through these holes the external air now enters and rises between the outer sheet-iron covering and the surface proper of the pile. In the course of from 40 to 48 hours afterwards, according to the temperature of the air, the pile will have become perfectly cool. The charcoal is drawn out through the three doors, *fff*, and the men who creep through them for that purpose are said to run no risk of being asphyxiated or oppressed by heat.

The following results are reported to have been obtained by charring, according to Dromart's process, silver fir wood in piles of the capacity of about 50 cubic metres :—

TABLE SHOWING THE RESULTS OF CARBONIZATION BY DROMART'S PROCESS.

| | I. | II. | III. | IV. | V. |
|---|------|------|------|-----|----|
| Volume of wood stacked .....Cubic metres | 47 | 42 | 44 | 48 | 48 |
| Volume of wood consumed in heating .. | 7 | 6 | 7 | 7 | 5 |
| Volume of charcoal produced | 31.5 | 29.5 | 28 | 36 | 32 |
| Yield of charcoal by volume per cent. of the wood | 59 | 62 | 55 | 65 | 60 |
| Duration of the process .....Hours | 42 | 34 | 42 | 48 | 24 |

I. Sapwood felled the year before, but very wet with rain.

II. Sticks of sapwood from 0.10 to 0.15 metre in diameter, cut the year before and very dry.

III. Sticks of sapwood from 0.10 to 0.16 metre in diameter, quite green and wet with rain.

IV. Thick logs of old resinous wood, quite dry.

V. Sticks of old resinous wood from 0.06 to 0.08 metre in diameter, cut the year before and quite dry. The yield somewhat exceeded 60 per cent. in volume.

It will be seen that green and wet wood gave the least yield. It is added that, at Léon, Dromart's process had been conducted in half the time above stated, but not with a smaller yield.

The costs of the charring, of which the results are given in the table above, are reported as under :—

A single apparatus is capable of carbonizing in 11 months 3300 cubic metres of wood, and producing therefrom at the least 1980 cubic metres of charcoal, the value of which, taking the price of charcoal at 10 francs per cubic metre, amounts to..... Francs 19,800

The items of cost of the wood and of charring are :—

| | |
|--|--------------|
| Labour for moving, at 1 fr. 50 cent. per cubic metre of wood ... | 2970 |
| Interest on the capital expended on plant | 300 |
| Deduction on account of sinking fund | 600 |
| Taking the apparatus to pieces five times and setting it up again, inclusive of carriage | 500 |
| | <hr/> 4,370 |
| Profit..... | <hr/> 15,430 |

It is asserted that the same quantity of wood carbonized in circular piles in the usual manner yields only 1000 cubic metres of charcoal, the value of which, taking the price of charcoal at 10 fr. per cubic metre, amounts to Francs 10,000

| | |
|---|-------------|
| Deducting for labour, etc. at the rate of 2 fr. per cubic metre | 2,000 |
| Profit | <hr/> 8,000 |

Hence, it is inferred that the difference of profit in favour of Dromart's process amounts to nearly 100 per cent.

Without imputing intentional misstatement to the inventor, the accuracy of his comparative estimates in the case of his own and that of the old method of charring may fairly be questioned, because he gives the yield by volume of charcoal from the latter as only 30 per

cent., which is much less than has been generally found in various localities in Europe. He maintains that in his process no free oxygen can enter the pile, and that the temperature is never high enough to cause the aqueous vapour, liberated from the wood, to act upon the charcoal, and convert any portion of it into carbonic acid, carbonic oxide, and marsh-gas—whereas, he alleges, the reverse is the case in the old method; that the quality of the charcoal is uniform, even where it is in direct contact with the air-pipes on the bed, and that any brown charcoal is very rarely found; and that there are no explosions, such as occur in the old process, and are attended with the projection to a considerable distance of pieces of ignited charcoal or wood, which in summer may set fire to a forest consisting of highly resinous fir-trees. On this account charcoal-burning is said to be forbidden in such forests in France during summer, but Dromart's process may be continued throughout the year without risk of producing such an accident.

It must not be supposed that, because a detailed description of this process has been given in the preceding pages, it is recommended for adoption. Although the value of the invention can only be decided by experience, yet, on theoretical grounds, objections may be urged against it, of which the chief appears to be the complicated construction of the apparatus, and the difficulty of so adjusting the sheets of wrought-iron as to make the pile "hermetically" close. Moreover, as the pile during carbonization is surrounded with a second series of sheets of iron, it would assuredly be difficult, if not impossible, to detect and stop up apertures through which air might get access to the interior and cause waste of wood or charcoal by combustion.

CHARRING IN RECTANGULAR PILES.

Charcoal-burning in large rectangular piles is extensively practised in some parts of Sweden. The following description of the process is taken from that of Af Uhr,⁷ altered in accordance with modern practice (January 1873) by G. Svedelius of Stockholm, author of a work On Charcoal-burning in Piles (*Om Kolning i Måla*, Stockholm, 1872). The ground on which the pile rests should be solid, dry, even, free from roots and stones, and should slope gradually from one end to the other, about 18 inches in 24 feet. The base is sometimes a square of about 19·5 feet on the side, but more frequently a rectangle of about 19·5 feet across the pile from side to side, and 23·5 or 24·5 feet in the opposite direction, i. e. in that of the slope. Upon the ground, in the direction of the slope, three poles, *a a a*, fig. 47, are placed parallel to each other, one in the middle and the other two about 2 feet from the sides of the pile respectively. These poles may be 6 or 7 inches in diameter at one end, and 4 or 5 at the other; the thickest ends

⁷ *Anleitung zur vortheilhaften Verkohlung*, p. 35; Giessen, 1820. See also *Notes by Durocher, Ann. des Mines*, s. 5, 1856, ix. 359. I have also received a MS. description from my friend Andreas Grill, of Sweden.

should be placed at the upper part of the slope. At the low end or *foot* of the pile are firmly fixed two posts, *b b*, inclining somewhat towards the pile, and supported by props on the outside, *b'*, fig. 48. At this end and all along the bottom, the longest and thinnest pieces of wood are placed crosswise on the three poles forming the foundation. The largest pieces should be placed in the centre, and towards the high end or *back* of the pile, where the exposure to heat will be longest. The large and small ends of the pieces should be placed

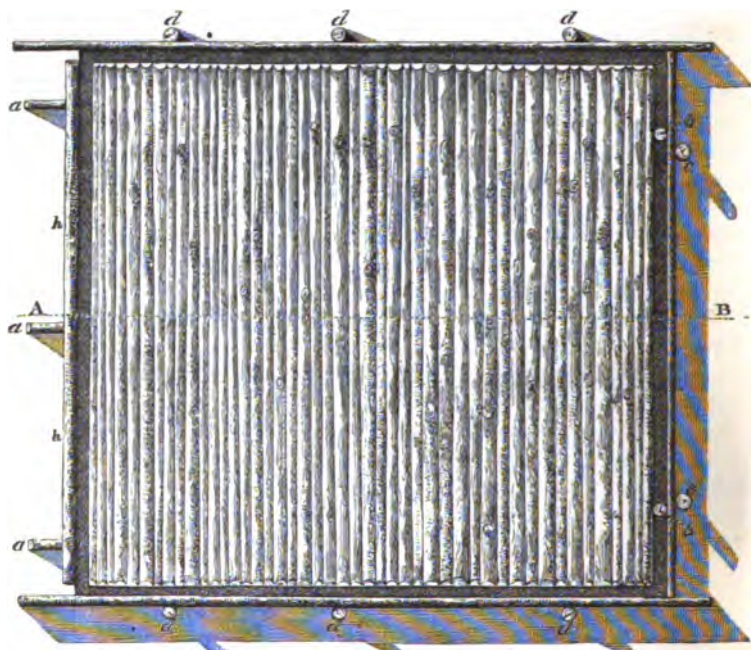


Fig. 47. Plan of a rectangular Swedish pile. Copied from plate 3 of Af Uhr's Treatise. The inclined props on each side and at the low end have been omitted.

alternately, so that the pile may be level and compact; the interstices between the larger pieces of wood must be filled, from side to side of the pile, with smaller pieces of wood, and the sides formed by the ends of the pieces of wood should be even and vertical. It is not necessary to split the wood, for Af Uhr found that pieces 23 ft. long, 2 feet in diameter at one end, and rather more than $1\frac{1}{2}$ at the other, were as thoroughly carbonized in piles of this description as the smaller pieces near them. It is hardly necessary to remark that wood of these dimensions is not used for charcoal-burning when it can be more profitably disposed of as timber. Hollow pieces of wood must be split, or else filled with small pieces. A horizontal channel or fire-hole, *k*, figs. 48 and 49, 6 or 8 inches square, should be left *through* the pile from side to side, near the low end at about 1 foot from the top; and should be well filled with small wood, very dry so as to be easily ignitable. At the back the lowermost piece of wood, *f*, should be let

into the three poles underneath. Into this piece, at about 3 ft. from each end, is let, at right angles, a wedge-shaped piece of wood, *g*, about 3 ft. long and 3 or 4 inches thick at the thick end, which is directed outwards, towards the back of the pile. Into the wedges, a second piece of wood is let transversely, and so wedges and transverse pieces of wood alternate until the pile is completed, as shown in fig. 48. By means of these wedges the transverse pieces of wood, *ff*, etc., are supported and fixed; and from the bottom to the top of the pile, at this end, is formed a series of parallel openings, which extend inwards as far as the thin ends of the wedges, and which are intended as vents. In addition to the two posts, *cc*, in front, there are three posts, *ddd*, fig. 49, fixed in the ground on each side of the pile, supported by props, *d'd'd'*. The upper surface of the pile is made even by covering

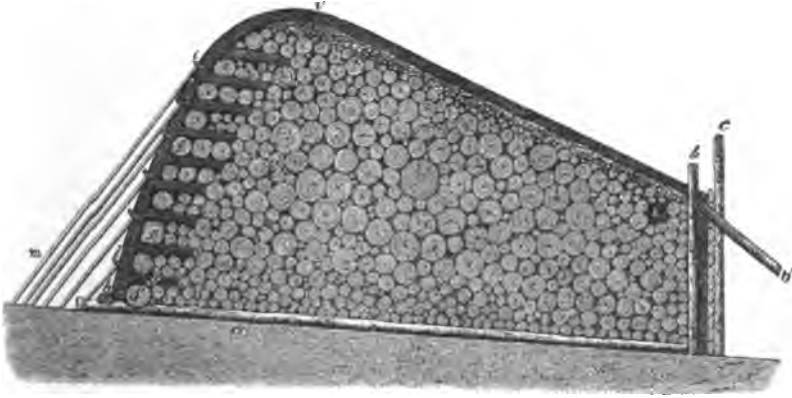


Fig. 48. Longitudinal vertical section of a rectangular Swedish pile, along the line *A B*, fig. 47. Copied from plate 4 of *Al Uhr's Treatise*. Svedelius states that the horizontal transverse pieces of wood, *fff*, etc., are in reality placed much nearer each other than they are represented to be in this woodcut.

it with a layer, 4 inches thick, of small pieces of wood. The larger interstitial spaces in the sides of the pile must be packed with suitable pieces of wood, and the smaller ones with brushwood. The upper surface of the pile is next covered with fir branches or twigs of sufficient thickness to feel soft under foot. Over the low end and the upper transverse pieces of wood at the *back* the brushwood is bent down, and the depending ends inserted in the interstices of the pile. The sides of the pile are also covered thinly with brushwood, by sticking the thick ends into the spaces between the pieces of wood, and bending the other ends down. The pile is thus prepared to receive its outer carbonaceous or black coating of *breeze* from previous burnings, mixed in a greater or less degree with soil. Chips, twigs, small charcoal, and the like, are carefully picked out of the breeze, which is to be used for the black coating; for if they were left, they might cause irregularity in the admission of air into the pile. The black coating is first spread over the brushwood on the top, to the depth of 4 or 5 inches. At the back of the pile a

piece of wood, *h*, figs. 47 and 48, is let into the projecting ends of the poles, *a a a*, at a distance of about 6 inches from the wood forming the back. The space thus left is filled with breeze, which is gently pressed down and added until it forms a wall 7 or 8 inches above the piece, *h*. Upon this wall is placed a piece of wood, *i*, fig. 48, extending from one side of the pile to the other. A second course of breeze is built on this piece of wood, and the process is repeated until at length the whole of the back of the pile is well coated. These transverse pieces of wood, *i*, are supported by props, *m*, as shown in figs. 48 and 49. On the sides of the pile at the bottom, stones about 5 or 6 inches high are laid at intervals, and on these is built up a wall of small or split wood, which is supported by the upright posts, *d d d*, which are firmly stayed, as above mentioned, by the inclined posts, *d' d' d'*, fig. 49.^s There should be a clear space of

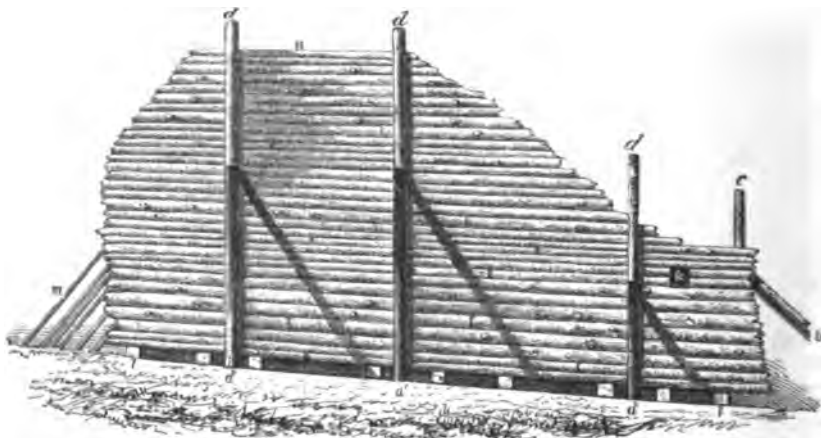


Fig. 49. Side elevation of a rectangular Swedish pile. Copied from plate 4 of Af Uhr's Treatise.

5 or 6 inches between the inner side of the wall of wood, and the sides of the pile formed by the ends of the wood intended for carbonization. This space is filled with carefully cleaned breeze simultaneously with the building up of the outer wall of wood; but openings are to be left in the outer walls of wood to the ends of the fire-hole, *k*, by the insertion and subsequent withdrawal of small pieces of wood. The front of the pile is completed by a wall of wood, and a packing of breeze, in the manner above described. Between the stones on the ground at the sides and front, and under the crosspiece of wood, *h*, at the back, suitable vents can be opened round the bottom of the pile. Care must be taken to stop any openings in the angles at the back, formed by the ends of the transverse pieces of wood, which support the cover, and the outer side-walls of wood.

When ready, the pile is lighted through the fire-hole, *k*, fig. 49, on

^s Only the foreground in fig. 49 is shown in perspective.

the side which at the time may happen to be least affected by the wind. When the fire has reached about one-third of the width of the pile as at *s*, fig. 50, the end of the fire-hole, on this side, is closed, while the opposite end, where the air for combustion of the small wood in the fire-hole must enter, is left open. Small vents, of about 1 inch in diameter, are then made *successively* in the cover down to the fire-hole, *k*, in order to draw the fire towards the opposite end, as indicated by the direction of the arrow in the annexed woodcut, fig. 50; and, when the fire has reached this end, the fire-hole is entirely closed. With dry wood it may require a day to light the pile; but with wood which is not dry, the lighting may occupy a day and a half, or even two days. The object should now be to cause the fire to extend equably through the wood *along the cover above* towards the back, and also *downwards* to the bottom of the pile. The fire is easily made to extend downwards, by air rising from the bottom of the low end through the pile. To draw the fire towards the back of the pile some vents are made in a line across the cover, at a distance of 5 or 6 feet in front of the fire, *i. e.* nearer the high end of the pile. As the fire advances gradually along the cover, and the smoke which issues from the vents becomes light, they must be stopped up, and others made nearer the high end of the pile. When the fire has reached the summit of the pile, vents must be made over the uppermost transverse piece of wood at the back of the pile; and the whole cover should then be well stamped down, and an additional thickness of about 3 or 4 inches of breeze added to it, to check the passage of gases through it. Carbonization is to be made to proceed gradually downwards from the cover to the bottom of the pile, by means of the last-mentioned row of vents, which are successively replaced by other rows, lower and lower down the back of the pile; to which air obtains access, by means of a row of vents made at this period along the bottom of the back of the pile. Lastly, vents are made at the bottom of the pile along the sides; and when it appears that the lowest stratum of wood has been carbonized, all the remaining vents are closed, and the pile is everywhere rendered as impervious to air as possible. Wherever the wood feels loose under foot, on walking over the top, it is a sign that carbonization is completed, and the cover over that part of the pile should then be beaten down, and made thicker. Owing to the contraction of

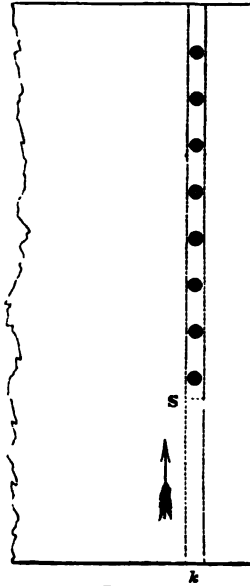


Fig. 50.
Diagram representing the top of the low end of the pile. The dotted parallel lines indicate the fire-hole, which extends from *k* to the opposite side. The round spots between these lines indicate the openings through the roof or cover, but are shown larger than they are actually made.

the wood by carbonization, the cover gradually sinks to a certain extent; and this sinking should take place uniformly across the pile, from one end to the other, without the formation of any steep ridge or irregular projections. If the wood is dry when stacked, carbonization always goes on better and more easily. The vents are made with a shovel through the coating of breeze into the twig covering; and sometimes they are made deeper by means of an iron bar. When the charring has extended throughout the whole pile, the cover is gradually taken off, beginning at the foot, and the charcoal lightly quenched with water. It is then removed to a store-house, where it remains until winter, when the roads become suitable for its transport to the furnaces.

DESCRIPTION OF CHARRING IN RECTANGULAR PILES BY KARSTEN.—The wood, sawn into lengths of about 8 feet and uncleaved, is placed transversely so as to form a pile about 24 feet long, increasing in height from one end to the other. The bed may be horizontal or slightly inclining upwards toward the high end of the pile. Fig. 51 represents a side view of such a pile, partly in section.

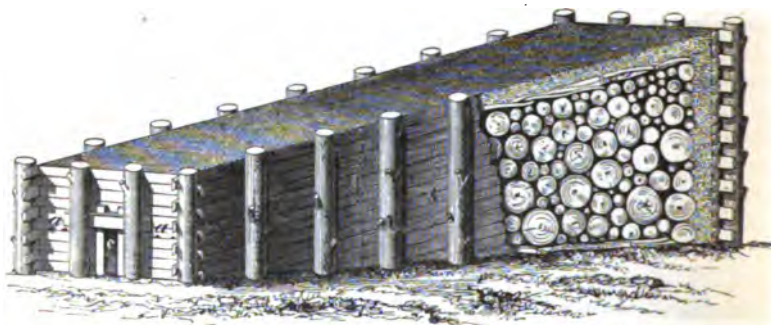


Fig. 51. A rectangular pile, shown partly in elevation and partly in vertical section.
Copied from Nos. 304 and 305 of Karsten's Atlas.

Immediately upon the bed, which is covered as usual with a layer, several inches thick, of small charcoal, long cleaved pieces or straight branches are laid in the direction of the long axis of the pile, and upon these the wood is placed crosswise at right angles. Thinner and dry pieces should be put at the low end where the pile is kindled. All round the pile, at a distance of about 6 inches, upright posts are driven firmly into the ground, at intervals of 2 or 3 feet. Boards are then fixed on the inside of these posts, and the space between them and the sides and ends of the pile is rammed with moistened breeze. The low end may be about 2 feet high, and the high end about 7 or 9 feet. The pieces are piled without reference to uniformity in size, but the largest should be put towards the high end. The interstices between the wood should be packed with the small wood of branches. The top of the pile is covered first with faggots and leaves, and afterwards with small charcoal in the usual way. The pile is ignited at the low end,

where a hole, *c*, is left for the purpose. As soon as light-blue smoke escapes from the cover at this end, the hole is closed. Three or four holes, an inch in diameter, are then opened through the breeze-coating, in the low end, about 15 inches from the ground, as seen at *a*, fig. 51. When, after some time, only light-blue smoke makes its way here and there through the cover above, it is a sign that carbonization is so far finished at the low end of the pile that air should be excluded from this part. The holes at *a* are then closed, and three or four fresh ones opened at *b*, 6 or 7 feet nearer the high end, about 2 feet from the ground, and 12 or 15 inches apart, and so the process is carried on to completion. The next holes should be made some inches higher, in proportion to the increasing height of the pile. After the closing of the holes at *a*, two or three fresh ones, of the same diameter, should be made underneath them, quite close to the ground. But these holes ought only to remain open until the appearance of a light, scarcely perceptible smoke. When the process has proceeded so far that openings have been made at 8 feet from the high end, charcoal may be begun to be drawn out from the low end, when it will rarely be found to be ignited. When the high end of the pile is actively burning, the charcoal from half of the pile towards the other end should be removed.⁹

MODIFICATION OF CHARRING IN RECTANGULAR PILES.—A pile, similar in form to the last described, is made by placing the wood lengthwise, and inclining upwards towards the high end, as shown in fig. 52. Stems which are more than 9 inches in diameter must

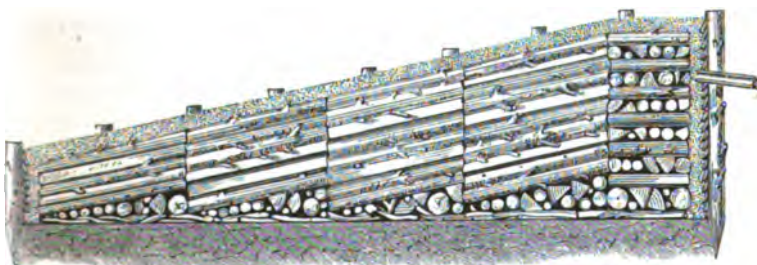


Fig. 52. Longitudinal vertical section of a rectangular pile.
Copied from No. 307 of Karsten's Atlas.

be cleaved. The interstitial space is less than in the last method; and, owing to the direction of the wood, carbonization is more rapidly propagated through the pile. In large piles of this form, the products of distillation may be collected by inserting cast-iron pipes, *p*, in the high end, and connecting these with a barrel to act as a receiver. The pipes must be kept cool by water flowing over them.

⁹ Karsten, *System der Metallurgie*, iii. 71 *et seq.* I have availed myself of Karsten's description, condensed as much as possible.

STAGES OF CHARRING IN CIRCULAR AND RECTANGULAR PILES.

The process of charcoal-burning in piles has been divided into three stages.

In the *first* or sweating stage (*Schwitzen*) desiccation of the wood is chiefly effected; one portion of the steam produced escapes through the cover, and another condenses and appears especially round the bottom of the pile. The hygroscopic water thus evolved is increased by that derived from the wood undergoing carbonization.

When this stage is completed, the heat, existing in the upper and central parts of the pile where charring is still chiefly going on, has so much increased, that the supply of air should then be very much reduced by closing, in a greater or less degree, the openings round the base of the pile. This constitutes the *second* stage (*Treiben*).

Currents of air are next established successively in various parts of the pile, by making vents in the cover, and other openings round the base; and so, by a carefully regulated combustion, the wood at the circumference is finally converted into charcoal. This is the *third* stage (*Zubrennen*).

Admission of air to every part is then stopped as completely as possible, and the pile is left to itself for a day or so, when the charcoal is withdrawn and extinguished by water or otherwise.

The foregoing remarks apply generally to charring both in circular and rectangular piles, but specially to the former.

CHINESE METHODS OF CHARRING IN PITS AND ARCHED CHAMBERS.¹

Two methods of making wood-charcoal are practised in China. When the soil is sandy, charring is effected in pits; and when, on the contrary, it is clayey and the locality is suitable, arched chambers are excavated, in which the wood is carbonized. The last method is preferred by the Chinese, who have carried it to such a degree of perfection that all the small branches and twigs are carbonized without losing their form.

THE FIRST METHOD.—The pits are circular, and are never deeper than 1·8 metre (6 ft.), but they sometimes exceed 4·3 metres (14 ft.) in diameter.² In the annexed woodcuts, figs. 53 and 54, the pit, *a*, is shown in vertical section and in plan. *b* is a round chimney of which the base is from 0·2 metre (8 in.) to 0·35 metre (14 in.) below the bottom of the pit; it rises about 1 metre (3 ft. 3½ in.) above the ground, and is connected with the pit by an oblong opening, *c*, not exceeding 0·35 metre (14 in.) in length, and from 0·05 metre (2 in.) to 0·1 metre (4 in.) in depth; the dimensions of this opening depend upon the quantity and the size of the wood to be charred. In pits 4·3 metres (14 ft.) in diameter, the chimney at

¹ De la Fabrication du Charbon de Bois en Chine. Par M. Kovanko, Major au Corps des Ingénieurs des Mines. Annuaire du Journal des Mines de Russie, année 1838, p. 375. St.-Petersbourg, 1840. I have given

nearly a literal translation.

² In reducing the French to English measures I have avoided fractions, and given the nearest whole numbers.

the base is 0.35 metre (14 in.) in width, and narrows upwards to 0.18 metre (7 in.) in width. In that part of the pit which is opposite the chimney is an inclined conical channel, from the lower end of which a vertical cylindrical chimney, E, 0.1 metre (4 in.) in diameter, rises to the surface. The axis of the conical channel ought to have such an inclination that its lower or narrow end is about equidistant from the bottom and upper edge of the pit. The bottom of the pit is covered with a bed of dry branches, upon which the wood is piled vertically, taking care, as usual, to leave as little interstitial space as practicable. When the pit is filled, the wood is covered first with small branches and then with a layer of soil sufficiently thick to be impervious to smoke. The wood is lighted through the opening, E, opposite the chimney which is left open; but occasionally ignition is facilitated by making a small hole above, at about 0.25 metre (10 in.) from the chimney, and closing it as soon as smoke begins to escape. If the smoke is copious, the pit is covered with stones, a small opening only being left to promote combustion. Five days after lighting the smoke begins to get purer; and when it has become quite transparent, the pit and chimney must be hermetically closed. Five or six days suffice for the complete extinction of the charcoal, after which the pit may be opened. Experience in China has shown that the more freshly the wood is cut, the less is the loss: 100 pounds of freshly-cut wood are stated to yield from 30 to 35 of charcoal, which, judging from experience in Europe, cannot be correct if black charcoal of good quality is produced. When a large quantity of wood is to be charred, the pits are made wider, but not deeper.

THE SECOND METHOD.—The arched chamber, excavated in the clayey ground, is 1.4 metre (4 ft. 8 in.) high and 4.3 metres (14 ft.) wide. A lateral chimney is formed just as in the first method. In the side of the chamber opposite the chimney there is a conical channel of which the base is directed towards the chamber and extends nearly to the arch, while the top is about intermediate between the bottom and the arch above. The chamber is entered by a low door, which is closed with stones as soon as the charging is completed. The wood is placed horizontally, with the usual precautions as to interstitial space. Ignition is effected through the channel opposite the chimney; and when

Fig. 53.

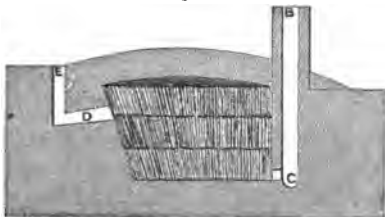
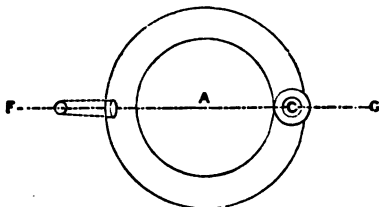


Fig. 54.



Chinese method of charcoal-burning in pits.

Fig. 53, vertical section on the line F G, fig. 54.
Fig. 54, plan of the pit.
Copied from Kovanko's engraving, which does not accurately agree with the description.

the smoke begins to issue from this channel, it is closed with stones, a very small opening only being left for the passage of the air. At the end of the charring the same course is followed as in the first method.

When a judgment respecting the stage of the process cannot be formed from an examination of the smoke, one or two freshly-cut sticks of the size of the finger are placed across the chimney; and when these sticks, impregnated with oil, become dry and their fracture black, it is a certain proof that carbonization is ended.

CHARRING IN OVENS.

I am indebted to my friend Andreas Grill for a description of this process as carried on at the Dalfors Ironworks, Sweden; and for the drawings from which the annexed woodcuts, figs. 55-57, have been executed. The works belong to his brother-in-law, the Hon. W. Didron, formerly member of the Swedish Iron Board, who expresses himself well satisfied with the process, and who, from his practical knowledge of the smelting and manufacture of iron, is well qualified to judge on such a subject. *aa* is the body of the oven, enclosed above by the arch, *bb*, which rests on the side-walls, *b'b'*, supported by buttresses, *b''b''*. The oven is filled as closely as possible with layers of wood, first through the lower openings, *cc*, and then through the higher ones, *c'c'*: these openings are afterwards closed as tight as possible by cast-iron doors, and all fissures are stopped up with clay. During the whole time of charring much care is required to prevent the admission of air through the sides of the kiln. A sunk passage, *d*, leads to the fireplace, *d'*, which is simply a cavity lined with fire-bricks and without any grate; from the fireplace there proceeds a flue, *d''*, fig. 55, which ends in a cross-flue and communicates with the interior of the oven by four openings, *eeee*, covered with a cast-iron plate, *e'*. Thus the fire passes immediately to the wood, and the volatile products of carbonization are carried off through the small round openings, *ff*, in the two alternate corners of the oven. These openings are prolonged by iron pipes, *f'f'*, terminating at the bottom of the chimneys, *f''f''*, which are provided with sliding dampers, so that, after the completion of carbonization, all connection may be cut off between the chimneys and the interior of the oven. The chimneys are made of wooden planks, and stand in wooden troughs, *gg*, filled with water. The condensed tar flows into these troughs, the floor of the oven being made slightly to incline towards the holes, *ff*. There is no difficulty in carrying on the process, care being taken to stop up all apertures from which smoke improperly escapes. When the process is terminated, which is indicated by the light colour of the smoke, the fireplace is closed with a cast-iron plate and walled up with bricks and mortar. The chimneys are also closed, and the whole left to cool.

These ovens are not much used in Sweden, but are more used in Finland, and can only be economically employed in peculiar localities, where the works are situated on the banks of a lake or river in the vicinity of a large tract of forest, of which the wood may be readily

conveyed by floating. It will not pay to carry wood in a forest to any considerable distance for charcoal-burning, so that when ovens are employed it is necessary to erect new ones, or remove old ones so

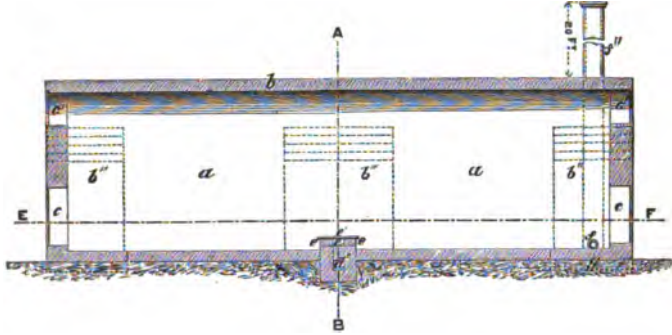


Fig. 55. Swedish oven for charcoal-burning. Vertical section on the line C D, figs. 56 and 57.

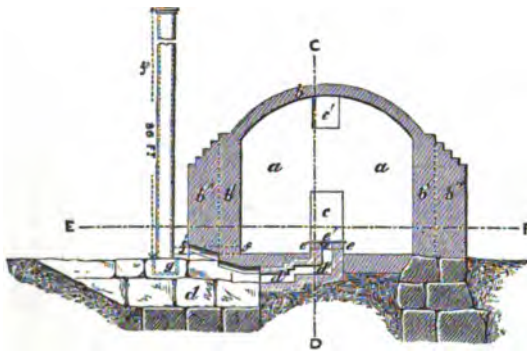


Fig. 56. Swedish oven for charcoal-burning. Vertical section on the line A B, figs. 55 and 57.

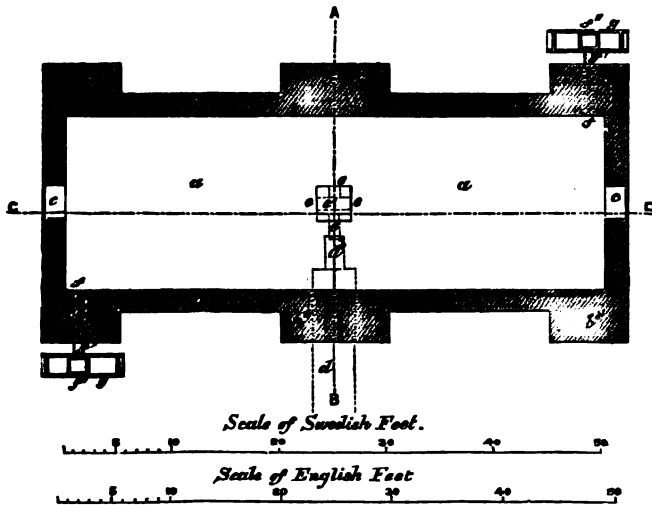


Fig. 57. Swedish oven for charcoal-burning. Horizontal section on the line E F, figs. 55 and 56.

THEORY OF CHARRING IN PILES.

From the mode of conducting the process of charcoal-burning in circular piles, it might be inferred that the combustion is propagated from above downwards, and from the centre to the circumference; and Ebelmen has confirmed the truth of this inference by the following experiment.³ A pile containing 30 cubic metres (1059 cub. ft.) of oak, beech, and fir, in pieces 0·7 metre (2 ft. 4 in.) long, was made in the usual way. In the centre was a chimney 0·25 metre (10 in.) in diameter, extending from the bottom to the top of the pile, and around it the wood was stacked in three layers, one above another; the large pieces being placed in the centre and the small outside. The diameter of the pile was 7 metres (22 ft. 11½ in.), and the height about 2 metres (6 ft. 7 in.). It was covered all over as usual with soil and breeze. It was lighted in the morning by putting ignited charcoal into the chimney, which was left open for some hours. Vents were made all round the bottom of the pile, and remained open during the whole process to supply air for the combustion. When the pile was sufficiently ignited, the chimney was filled with small wood and then closed. In the evening the vacant space caused by the burning away of the wood in the chimney was filled with breeze. This was again done next morning. In the course of the day vents were made in the covering of the pile near the top. The smoke which escaped from them was white, thick, and copious; but after some hours it became bluish, almost transparent, and much less abundant; then the charcoal-burner made fresh vents, about 0·2 metre (8 in.) or 0·25 metre (10 in.) below those above. On the third day, when the vents were 1·2 metre (3 ft. 11½ in.) above the ground, half of the pile was removed, and the ignited wood and charcoal were extinguished with water. The annexed woodcut, fig. 58,

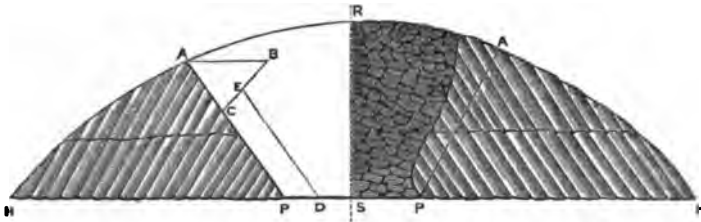


Fig. 58. Diagram showing the gradual course of the charring of wood in circular piles.
Copied from Ebelmen's figure.

shows the condition of the pile at this time. The charcoal was all contained within the space produced by the revolution of the plane $ABRS$ round the axis RS . This space represents nearly an inverted truncated cone, of which the radius of the small base next the ground is about 0·4 metre (1 ft. 4 in.). In the rest of the pile the wood was unchanged, the pieces being only blackened on the surface by tar, and

³ *Recueil des Travaux scientifiques*, ii. 104 *et seq.* I have as far as practicable literally translated Ebelmen's language.

exhaling an empyreumatic odour; on sawing them across it was evident that they had not even begun to undergo desiccation. The greater part of the charcoal contained within the space $\triangle RSP$ was in pieces placed irregularly as in a heap of charcoal, and without any connection with the surrounding wood. It was only in that part of the pile corresponding to the triangle $\triangle ABC$, and the space included between the line AP and the parallel line ED , by their revolution round RS , that the charcoal remained attached to the wood. The distance between DE and AP was from 0.1 metre (4 in.) to 0.15 metre (6 in.). On each of the pieces of wood included within this space, the passage from perfect charcoal to unchanged wood might be traced, the two being separated by partially carbonized brown wood to the distance of 0.07 metre ($2\frac{1}{2}$ in.) or 0.08 metre (3 in.). The carbonized part of the wood had undergone very sensible contraction. If carbonization had been allowed to proceed unchecked, the angle HDE would have continued to decrease, until at length the line DE would have coincided with HD , and then all the wood would have been converted into charcoal. Hence it is clear that carbonization in piles is propagated from above downwards, and from the centre to the circumference.

The air enters at the bottom of the pile, and finds its way to the space within $\triangle P$, to which combustion is limited; and the volatile products of carbonization escape at vents above $\triangle B$, round the upper part of the pile. It is in the spaces $CEDP$ and $\triangle ABC$ that the charcoal last formed remains attached to the wood. But as the volume of charcoal is considerably less than that of the wood from which it is produced, the spaces between the carbonized parts of the pieces of wood must be considerably greater than between those which remain uncarbonized. But within the space $EDSR$ the charcoal is detached, broken, and irregularly piled in a heap. Hence, the circulation of air should take place most readily where the least resistance is offered; that is, upwards through the space $CEDP$, with the upper part of which the vents are in communication.

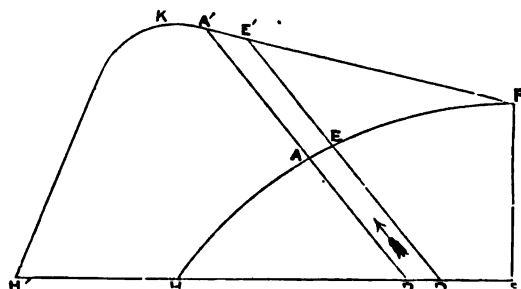


Fig. 59. Diagram showing the gradual course of the charring of wood in rectangular piles.

In the rectangular pile the process of carbonization would appear to take place in much the same manner as in the circular pile. In the preceding diagram, fig. 59, let RHS represent the left half of the

vertical section of a circular pile (see fig. 58), and let RKH 's represent the vertical section of the rectangular pile, fig. 48. Now in the circular pile carbonization commences along the line RS , and proceeds outwards and downwards till it approaches the line ED . Suppose the wood within the space $REDS$ to be already converted into charcoal, and the process of carbonization to be active within the space $EAPD$, the air by which combustion is sustained circulates upwards in the direction of the arrow. But this is certainly the direction in which the air circulates through the rectangular pile RKH 's. In the circular pile the smoke escapes through vents all round on a level with A ; whereas in the rectangular pile it escapes through vents across the top at A' .

SOURCE OF THE HEAT BY WHICH CARBONIZATION IN PILES IS EFFECTED.

According to Ebelmen, the heat by which carbonization is effected in piles is produced solely by the combustion of the charcoal itself, and not in any degree by the combustion of the volatile products evolved during the formation of the charcoal. He analysed the volatile products which issued from the vents of piles in different stages of charring, and those which are produced by the carbonization of wood in *close* vessels. In the case of the pile, the permanent gases will contain all the nitrogen of the air which has contributed to sustain combustion, together with an amount of carbonic acid corresponding to the oxygen of that air; that is, admitting that the oxygen is wholly converted into carbonic acid by contact with the ignited charcoal of the pile. Now, if we deduct from these permanent gases all the nitrogen, and an amount of carbonic acid containing oxygen, proportionate to the amount associated with nitrogen in atmospheric air, the residual gases will be found to approximate in composition to the permanent gases produced by the carbonization of wood in close vessels. The following experimental results in proof of this were obtained by Ebelmen. In the following table is given the composition of the permanent gases which he collected from piles, and in the succeeding table a correction has been made for the nitrogen and the amount of carbonic acid containing the quantity of oxygen associated with the nitrogen in the atmosphere:—

I. TABLE SHOWING THE PERCENTAGE COMPOSITION BY VOLUME OF THE PERMANENT GASES EVOLVED DURING CHARCOAL-BURNING IN PILES.

| Constituents. | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. |
|--------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Carbonic acid..... | 25.57 | 26.68 | 27.23 | 25.89 | 28.34 | 21.26 | 23.51 | 23.28 | 28.08 |
| Carbonic oxide ... | 8.68 | 9.25 | 7.67 | 9.33 | 15.17 | 5.18 | 5.00 | 5.88 | 6.04 |
| Hydrogen | 9.13 | 10.67 | 11.64 | 9.28 | 8.87 | 8.84 | 4.89 | 13.53 | 14.11 |
| Nitrogen | 56.62 | 53.40 | 53.46 | 55.50 | 47.62 | 64.72 | 66.60 | 57.31 | 55.77 |
| Total..... | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 99.00* |

* In Ebelmen's work the sum of these numbers is given as exactly 100; the error is probably typographical.

II. TABLE SHOWING THE PERCENTAGE COMPOSITION BY VOLUME OF THE SAME GASES AFTER DEDUCTION OF THE NITROGEN AND CORRESPONDING CARBONIC ACID.

| Constituents. | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. |
|--------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Carbonic acid..... | 37.5 | 38.8 | 40.3 | 37.8 | 39.7 | 23.5 | 37.8 | 29.8 | 29.6 |
| Carbonic oxide ... | 30.4 | 28.4 | 23.6 | 31.2 | 38.0 | 28.2 | 31.4 | 21.2 | 21.1 |
| Hydrogen | 32.1 | 32.8 | 36.1 | 31.0 | 22.3 | 48.3 | 30.2 | 49.0 | 49.3 |
| Total..... | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.4* | 100.0 | 100.0 |

* In Ebelmen's work the sum of these numbers is given as exactly 100; the error is probably typographical.

(1.) Gas from the vent of a pile, at one-third of its height, two days after lighting. The pile contained 60 cubic metres (2118 cub. ft.). The vent had been opened 6 hours before, and gave much thick white smoke. A mercurial thermometer put in to the depth of 0.1 metre (4 in.), and taken out after 8 minutes, marked 260° C. (2.) Gas 24 hours after No. 1, from a vent in the same pile, opened an hour previously. There was much dense white smoke. (3.) Gas 24 hours after No. 2, from a vent in the same pile, at 0.6 metre (1 ft. 11½ in.) from the ground, opened an hour before. There was much white smoke. Temperature 230° C. (4.) Gas from a vent of another pile containing 35 cubic metres (1236 cub. ft.), at 0.6 metre (1 ft. 11½ in.) from the ground, 4 days after lighting. Much dense white smoke issued from this vent. (5.) Gas from the same pile as No. 4, at 0.3 metre (11½ in.) from the ground, and 18 hours before the termination of the burning. Dense white smoke. (6.) Gas from the vent of another pile, 0.6 metre (1 ft. 11½ in.) from the ground, and 36 hours before the termination of the burning. Smoke bluish, transparent, and not copious. (7.) Gas from the same pile as No. 1, 18 hours afterwards. The vent had been made 4 hours previously, and was 0.3 metre (11½ in.) below that from which gas No. 1 issued. White and not very dense smoke. (8.) Gas from the same vent as No. 7, but 5 hours afterwards. Smoke clear and slight. Temperature 250° C. (9.) Gas from the same pile as No. 8, 24 hours afterwards; the smoke which issued from the vent was slight, bluish, and almost transparent. The piles employed in these experiments were constructed like that described under the fourth modification of charring in circular piles (pp. 371-2).

Ebelmen has given the following results relating to the composition of the gases produced by the carbonization of wood in close vessels:—

PERCENTAGE COMPOSITION BY VOLUME OF THE PERMANENT GASES PRODUCED BY CARBONIZATION IN CLOSE VESSELS.

| Constituents. | 10. | 11. |
|-------------------------|-------|-------|
| Carbonic acid..... | 44.9 | 29.2 |
| Carbonic oxide | 36.8 | 24.9 |
| Hydrogen | 16.8 | 44.2 |
| Nitrogen and loss | 1.5 | 1.7 |
| Total..... | 100.0 | 100.0 |

The wood was subjected to distillation in a small iron retort heated to cherry-redness. (10.) Gas half an hour after the retort was put into the furnace. Thick, white, irritating, and non-inflammable smoke issued. (11.) Gas $1\frac{1}{2}$ hour after the beginning of the carbonization; it burnt spontaneously with a blue flame as it issued from the retort.

It will be observed that in both methods of carbonization the proportion of hydrogen greatly increases towards the end of the process, while, at the same time, the carbonic acid and carbonic oxide decrease. At the end of the carbonization, in both cases, the composition of the permanent gases is very similar.

Ebelmen made three determinations of the amount of condensable matter evolved during carbonization in piles, and one of the amount produced by distillation in a retort. For 1 litre (61.02 cub. in.) of dry gas reduced to 0° C. and 760 millimetres pressure, the weight of condensable matter was as follows:—

| | In a Pile. | | | In a Retort. | |
|----|------------|---------|----|--------------|---------|
| | Grammes. | Grains. | | Grammes. | Grains. |
| 1. | 0.987 | 15.232 | 4. | 2.812 | 43.395 |
| 2. | 1.068 | 16.481 | | | |
| 3. | 0.531 | 8.194 | | | |

(1.) From a vent 1 metre (3 ft. 3 $\frac{1}{4}$ in.) above the ground, opened an hour before; smoke dense and white. (2.) From a vent on the same level as No. 1 and 45 minutes afterwards. (3.) From a vent 1 metre above the ground. Smoke bluish and almost transparent, carbonization being far advanced in this part of the pile. (4.) Collected immediately after the gas, No. 11, at the top of this page.

In order properly to compare these results of carbonization in piles and retorts, those analyses of the volatile products produced during similar stages of the process should only be selected. Ebelmen accordingly takes the mean of the first five analyses of the permanent gases produced during carbonization in piles (after deduction of the nitrogen and corresponding carbonic acid), to compare with the mean of the two analyses of the permanent gases evolved in the retorts; and the mean of the first two determinations of the amount of condensable products evolved during carbonization in piles, to compare with the single determination of the amount produced in the retort. The following table will facilitate the comparison in question:—

TABLE SHOWING THE MEAN PERCENTAGE COMPOSITION BY VOLUME OF THE GASES AND THE PROPORTIONS BY WEIGHT OF THE CONDENSABLE VOLATILE PRODUCTS OF CARBONIZATION IN A PILE AND IN A RETORT.

| Constituents of the Gaseous Products. | From Carbonization in a Pile.* | From Carbonization in a Retort.† |
|--|--------------------------------|----------------------------------|
| Carbonic acid | 39·0 | 37·9 |
| Carbonic oxide..... | 30·6 | 31·2 |
| Hydrogen | 30·4 | 30·9 |
| Total | 100·0 | 100·0 |
| Weight of liquid products condensed in collecting 1 litre (61·02 cub. in.) of dry gas,‡ reduced to 0° C. and 760 mm. pressure. | 1·142 grms (17·621 grs) | 2·812 grms (43·395 grs) |

* Mean of Nos. 1 to 5, Table II., p. 392 *supra*.

† Mean of Nos. 10 and 11, p. 393 *supra*.

‡ In the case of the gas from a pile, the given volume was exclusive of the nitrogen, and of the carbonic acid corresponding to the oxygen associated with the nitrogen in atmospheric air.

§ This number should apparently be 1·027 grm., or 15·846 grains.

From the preceding data it would appear that the mean composition of the permanent gases produced during carbonization in piles and retorts is similar, though not identical. But this similarity of composition is only obtained by taking the mean of the two analyses, Nos. 10 and 11, of the gases from the retort, which were very dissimilar, especially in the proportion of hydrogen. Even on this ground alone it may be questioned whether the conclusion of Ebelmen, that the heat by which carbonization in piles is effected is produced exclusively by the combustion of carbon, is sufficiently proved. The evidence in favour of that conclusion, derived from a comparison of the liquid products, is still less satisfactory; and even if the similarity were greater than it is, a confirmation of the results would be required to justify any decided inference from them.

The method of analysis which Ebelmen adopted is incorrect. He passed the gases through a red-hot tube containing oxide of copper, and weighed the carbonic acid and the water produced, as in an ordinary organic analysis; by which method no evidence would be afforded of the presence of carburetted hydrogen, which recent investigations have proved to be a constituent of the permanent gases evolved during the dry distillation of wood.

It has been previously stated that ordinary charcoal retains a sensible amount of hydrogen (see p. 354), and if such charcoal be burned, it is impossible to conceive that during the process of charcoal-burning the carbon alone should be consumed, and the hydrogen wholly escape combustion. Indeed, Ebelmen himself has mentioned this objection, but remarks that it does not at all alter the conclusions which he has drawn from his experiments.⁴

But even if Ebelmen had established that the gases from piles and retorts were, after deducting the nitrogen and carbonic acid as

⁴ Recueil des Travaux scientifiques, ii. 123, in a note.

above mentioned, identical, still, as Scheerer remarks,⁵ it would not follow that carbonization in the former is due solely to the combustion of charcoal. In order to justify that conclusion, it must be shown that the nature and amount of condensable or liquid products are the same in both cases. It is, however, manifestly impossible to collect all the liquid products from a pile, as may be done from a retort; and that no decided conclusion can be drawn from the relation between these products and the permanent gases of piles (after abstraction of the nitrogen and of carbonic acid proportionate to the oxygen with which nitrogen is associated in atmospheric air) is clear from Ebelmen's own examination of a pile in process of carbonization. In that examination, it will be borne in mind, tarry matter was found condensed on the unchanged and partially charred wood. There is, therefore, no proof from Ebelmen's experiments that the amount of tar from piles and retorts is the same. It is true that the same amount of tar may be generated in both cases; but in the absence of proof, it cannot be admitted that in piles no tar is subsequently burned. By the perfect combustion of tar much heat may be developed, the products being carbonic acid and water. Now Scheerer explains how he conceives the composition of the permanent gases from piles—exclusive of the nitrogen and carbonic acid of which the oxygen has been derived from the air—may be the same as that of the gases from retorts; notwithstanding that in piles the volatile products may be partially burned. His explanation is as follows:—let it be granted that the relation between the gaseous and liquid products may, at the moment of their development, be the same in piles as in retorts. Suppose, then, that a portion of the volatile products of piles is partially burned by the action of atmospheric air, excluding from consideration any carburetted hydrogen which may be present. The products of such combustion would be *carbonic acid* from the *carbonic oxide*—*water* from the *hydrogen*—and *carbonic acid* and *water* from the *tar*. The original quantity of carbonic acid and water would, consequently, be increased; while, on the contrary, that of the carbonic oxide, hydrogen, and tar would be diminished. It is certain that a portion of the previously-formed charcoal is burned, and with the production, most probably, of carbonic acid, so that an addition of this gas would be made to that formed from the volatile products. It is inconceivable that all the carbonic acid and vapour of water should be exposed to the action of the ignited charcoal of the pile, and yet that none of the former should be converted into carbonic oxide, and none of the latter into carbonic oxide, carbonic acid, and hydrogen. Hence, from one source there would be an *increase*, and from another source a *decrease*, in the quantity of carbonic acid, and an increase in that of the carbonic oxide and hydrogen. It appears therefore probable from the preceding data, that a considerable proportion of the volatile products of piles may suffer combustion, and yet the permanent gases which

⁵ Lehrbuch der Metallurgie, i. 251.

escape from them—exclusive of those derived from atmospheric air—may only differ from the volatile products of retorts in containing a larger amount of carbonic acid, and in being accompanied with a smaller amount of tar. We may thus understand how the oxygen of the *excess* of carbonic acid in the gases of piles (beyond the proportion present in the gases of retorts) may have the same relation to the nitrogen as exists between these gases in atmospheric air. This relation must be exactly preserved if as much carbonic acid be produced by the action of the vapour of water on the ignited charcoal as there is of carbonic acid converted into carbonic oxide by the action of the ignited charcoal.

However plausible Scheerer's explanation may at first sight appear, it must yet be borne in mind that it does not rest on experimental evidence. In order that carbonic acid should be converted into carbonic oxide by contact with ignited carbon, it is necessary that the temperature should be much higher than that of mere ignition; but whether that degree of temperature exists in piles is not shown.

Supposing that there is perfect combustion of a portion of the tar produced in piles, it is easy to conceive how there may be identity between the composition of the permanent gases evolved from retorts and piles respectively—that is, after the deduction from the gases of piles of all the nitrogen and the proportion of carbonic acid corresponding to the quantity of oxygen derived from the atmosphere; for, as the products of the perfect combustion of tar are carbonic acid and water, the excess of carbonic acid may as well be derived in part from the combustion of tar as from the previously-formed charcoal. The amount of water, it is true, would be increased by the combustion of tar, and by so much would the volatile products of piles exceed those of retorts; but no facts have been adduced to show that the proportion of water from piles and retorts, *ceteris paribus*, is the same.

Scheerer has further attempted to oppose the theory of Ebelmen by proving that the amount of heat developed by the combustion of charcoal alone is far from sufficient to determine carbonization in piles; and if his datum be granted, that only 3 per cent. of charcoal is actually burned, his ground of opposition is fatal to the theory in question. However, in many recorded observations concerning the yield of charcoal by burning in piles, it is certain that much more than 3 per cent. has been consumed. As the evidence advanced on both sides is defective in scientific precision, probably the best course is to suspend judgment, and to admit that, while Ebelmen has failed conclusively to establish his theory, Scheerer has also failed satisfactorily to overthrow it.

YIELD OF CHARCOAL.

The yield will vary with the nature of the wood, with its age and condition, especially as to dryness, and with the mode of conducting the process of carbonization.⁶ Of all these causes of variation, the last is the most influential. The yield of charcoal may be computed by measure or by weight. In practice, estimation by measure is usually preferred, because the proportion of water in charcoal is far from constant; and unless special precautions were taken to expel this water before weighing, a very erroneous result might be obtained. But such precautions on the large scale would be impracticable.

In order to ascertain the yield by weight, the data required are simply the weight of the charcoal and the weight of the wood from which it is produced. But if by measure, several methods of computation may be adopted. One German writer enumerates not less than six different modes of estimating the yield of charcoal by measure.⁷ One of the most obvious methods, and that which is in use in this country, is to measure the charcoal and the wood, inclusive of the interstices between the pieces, the wood being supposed to be suitably stacked for the purpose. Thus the wood may, according to the usual practice, be estimated in cords, and the charcoal in bushels; and from the data thus obtained, the relation, in cubic feet, between the charcoal and the wood may be readily found. A cord is a pile of wood 4 feet broad, 4 feet high, and 8 feet long; and a bushel is 1.2836 cubic foot. When yield of charcoal by volume is mentioned in this work, the preceding method of computation is referred to, if not otherwise stated. A second method of estimating yield by volume is to compare the amount of charcoal as determined by measure, *inclusive of the interstices between the pieces*, with the amount of wood, *exclusive of the interstices between the pieces*; in other words, to compare the *apparent* volume of the charcoal with the *actual* volume of the wood. The amount of interstitial space in a closely packed pile of wood, consisting of uncleaved stems, may be taken at about 30 per cent. of the mass; but in the case of cleaved wood or branch-wood, this space may be estimated at from 40 to 50 per cent., or even 52 per cent.⁸ The statements of different authors do not, as might be expected, exactly agree as to the amount of interstitial space. At Hildau it is estimated at 25.5 per cent. in wood, and 36 per cent. in charcoal.⁹ A third method is to compare the *actual* volume of the wood with the *actual* volume of the charcoal, that is, exclusive of interstitial space both in wood and charcoal. In reading German works on charcoal-burning, it is necessary to remember these differences in

* Théodore de Saussure made numerous experiments in order to ascertain the yield of charcoal from the wood, bark, and leaves of different trees, and other vegetable substances carbonized under similar conditions, at the temperature of molten silver. *Recherches chimiques sur la*

Végétation, Paris, an xii (1804), p. 185.

⁷ Klein, *Ueber Verkohlung des Holzes in stehenden Meilern*, p. 155.

⁸ Scheerer, *Lehrbuch der Metallurgie*, i. 237.

⁹ *Ann. des Mines*, s. 3, 1835, vii. 6.

the estimation of the yield of charcoal by volume, otherwise much confusion and error may be the result. In some of these works elaborate formulæ are given for the estimation of the cubic contents of piles of different forms, but it is presumed that the reader is sufficiently acquainted with the mensuration of solids not to require any special formulæ of this kind.

YIELD OF CHARCOAL BY VOLUME.

In Sweden the average yield of charcoal is estimated at 63·2 per cent. of the volume of the wood of *Pinus picea* and *Abies excelsa*.¹ The extremes were 50·5 and 75 per cent. Comparative trials have been made in the same country to determine the difference of yield between piles in which the wood is stacked vertically, and those in which it is stacked horizontally; in the former the yield amounted to 67 per cent. and in the latter to 75 per cent. by volume. The ordinary yield of charcoal, however, is stated to vary from 60 to 65 per cent.² In regard to this point, Svedelius has favoured me (January 1873) with the following observation:—"As to the fact that the yield of charcoal from piles, in which the wood is stacked vertically, is generally some 5 or 8 per cent. less in volume than the yield from those in which it is stacked horizontally, it must be remembered that the amount of interstitial space is generally about 6 per cent. greater in the former than in the latter case."

In Upper Silesia the following yields have been obtained: 52·6 per cent. on the average from stem-wood, and occasionally 60 per cent.; 42·7 from branch-wood, and 39·5 from root-wood.³ Lampadius states that in the Saxon Erzgebirge the yield from the stem-wood of *Pinus picea*, in the best managed charcoal-burning in round piles, is as much as 80 per cent. in volume.⁴ At Hiflau, Styria, the yield from long piles of fir-wood was found to be 76·8 of large charcoal, and 2·7 of small, making a total of 79·5 per cent. in volume.⁵ At the same place the yield from large round piles has reached 86·2 per cent.⁶ In some cases the volume of charcoal is stated to have exceeded that of the original wood even to the extent of 28 per cent.

At the Horowitz Ironworks, in Bohemia, the yield of charcoal by volume from various kinds of wood has recently been published, and is shown in the following table;⁷ charring was effected in circular piles with the wood placed more or less vertically, and charcoal instead of wood supplied to the central chimney:—

¹ Af Uhr, quoted in Scheerer's Lehrbuch der Metallurgie, i. 238. Mr. Grill, of Sweden, confirmed this statement to the Author.

² Durocher, Ann. des Mines, s. 5, 1856, ix. 363.

³ Wittwer, Karsten's Archiv, 1851, xxiv. 293 et seq.

⁴ Grundriss einer allgemeinen Hüttenkunde, 1827, p. 48.

⁵ Ann. des Mines, s. 3, 1835, vii. 6. The species of fir is not stated.

⁶ Idem, p. 18.

⁷ Berg- und hüttenmännische Zeitung, 1871, p. 269.

TABLE SHOWING THE YIELD OF CHARCOAL BY VOLUME FROM VARIOUS KINDS OF WOOD IN BOHEMIA.

| Wood from that part of the Forest where the Trees are in regular course of being felled (<i>Holz aus offenen Schlägen</i>). | Volume of Charcoal per cent. of the volume of Wood, inclusive of interstitial space. |
|---|--|
| Billets (<i>Scheitholz</i> *) of beech, birch, and oak..... | 61-70 |
| Faggots (<i>Prügelholz</i>) do. do. | 52-60 |
| Branch-wood (<i>Astholz</i>) do. do. | 45-52 |
| Logs of Scotch fir and larch..... | 59-60 |
| Faggots do. do. | 50-55 |
| Branch-wood do. do. | 28-29 |
| Stump-wood (<i>Stockholz</i>) do. | 42 |
| Logs of silver and spruce fir (<i>Fichten</i> and <i>Tannen</i>) | 75-80 |
| Faggots do. do. | 65-70 |
| Branch-wood do. do. | 31-39 |
| Stump-wood do. do. | 49-56 |
| Wood from the thinning of the Forest (<i>Durchforstungsholz</i>). | |
| Hard wood..... | 51 |
| Scotch fir | 35-45 |
| Silver and spruce fir..... | 49-62 |

* *Scheitholz*. I cannot find a precise definition of this word in German, any more than I can of the word *log* in English. I am informed that it means pieces of stems cut or sawn across in lengths of from 4 to 5 feet, and either round and entire, or subdivided lengthwise, according as the stems are less or more than about 4 inches in diameter.

The forests near the Horowitz Ironworks are on the Silurian formation at an elevation ranging from 1070 to 2000 feet (Austrian) above the level of the sea; and the trees are of different kinds, occurring in the following proportions:—60 per cent. of pine (*Fichte*—it is not clear what species is intended), 20 of Scotch fir (*Kiefer*), 12 of silver fir (*Weisstanne*), 6 of larch, and 2 of birch, beech, and oak. The produce of the first and third kinds of trees, after 80 years' growth, amounts to 143 Klaftern (wood measure, = 12,870 English cubic feet) per Joch (= 1600 square Klaftern = 6321 English acres,—1 Klafter linear = 6 Austrian feet, of which 100 = 103·710 English feet); of the second and fourth kinds, after 60 years' growth, to 108 Klaftern (= 9720 English cubic feet), and of the fifth kind, or the beech forest, after 100 years' growth, to 117 Klaftern (= 10,530 English cubic feet) per Joch.

The discordancy between some of the results above given is so great that it cannot be attributed to the causes of variation previously mentioned, and must be due either to error of observation or to a variable or fallacious method of computation; and that the latter may in some instances have been the true cause, will appear from the following remarks. The volume of the wood may have been deduced from the cubic contents of the pile as determined by measurement. Now the amount of interstitial space may vary greatly in different piles, not only with the degree of compactness with which the wood is stacked, but also with the size and irregularity in shape of the pieces. The amount of the space, as Karsten remarks, could only be correctly determined by filling the interstices with sand, and afterwards measuring its volume; but no such determination seems to have been made, at least

on a large scale. In respect to the volume of charcoal, the amount of interstitial space may vary considerably, especially from the greater or less degree of splitting in the wood during carbonization. When the wood is not sufficiently dry, splitting may take place to a very sensible extent; and probably in this way the statement that the volume of charcoal has, in some cases, exceeded that of the original wood, may be explained. On this point Svedelius remarks:—"I am not persuaded that splitting may take place to a greater extent when the wood is less dry. Af Uhr at least has observed that the drier the wood, the greater the volume of charcoal." We know certainly that wood contracts sensibly in all directions by carbonization, and in length from 11 to 12 per cent. Cork, however, which is bark and not wood, increases in volume by carbonization.⁸ The degree of contraction will depend upon the kind of tree, its age, the part of the tree, and other circumstances. Young wood and branch-wood contract more than old or mature wood and stem-wood. In general, coniferous wood contracts less than other wood. Fir-wood, when young and soft, loses from 46 to 47 per cent. in *actual volume* by carbonization; but when old and strong, 44·5 per cent. In the case of non-coniferous wood, the hard kinds contract considerably more than the soft: the harder kinds of wood, and the young wood or branch-wood of the softer kinds, lose 52 per cent. in actual volume, whereas the mature wood of the softer kinds loses only 50 per cent. A yield of 55 per cent. in actual volume from coniferous wood, and 48 per cent. from non-coniferous wood, may be regarded in general as favourable.⁹

YIELD OF CHARCOAL BY WEIGHT.

The yield, by *weight*, of charcoal has been often determined; but, as might be expected, there is great discrepancy in the results which have been published on the subject. As various causes influence the yield in a marked degree, the observations of one author cannot well be compared with those of another, unless the precise conditions under which the charring has been effected are stated. The weight, however, may be considered as ranging between 15 and 28 per cent. of that of the wood. In different localities in the north-east of France, the yield from circular piles, containing from 60 to 90 cubic metres of wood, has been found to range from 17 to 21·33 per cent. in weight.¹ The kinds of wood employed were beech, oak, poplar, willow, and hornbeam. It is estimated in France that with good charcoal-burners an average yield of not more than 19 per cent. should be calculated on.² François found that in the Ariège, in the Pyrenees, in 1842, a pile containing 21 stères (1 stère = 1 cubic

⁸ Karsten, *Handbuch der Eisenhüttenkunde*, part 2, p. 267.

⁹ Karsten, *idem*, p. 268.

¹ Sauvage, *Ann. des Mines*, s. 3, 1837,

xi. 359.

² *Traité de la Fabrication de la Fonte*, etc. Par Flachet, etc. Part 1, p. 112.

metre) of beech wood, 19 years old and felled three weeks before stacking, yielded 0·338 cubic metre (weighing 76 kilogr.) of charcoal, per stère (weighing 445 kilogr.) of wood, that is, 17·07 per cent. of the wood by weight.³ In Belgium, from wood of 15 to 20 years' growth, a yield of 15 to 17 per cent. is obtained; and if the charring be slowly conducted, it may amount to 20 or 22 per cent. at the most. The wood employed consists of $\frac{3}{4}$ to $\frac{2}{3}$ of the hard kinds.⁴ In Sweden, the yield from *Pinus sylvestris* and *P. picea* by charring in circular and rectangular piles has been found, according to Af Uhr, to range from 20 to 28 per cent.⁵ A yield of 22 per cent. in weight may be regarded as very favourable.⁶ The average yield of twenty-six recorded observations on charring in piles in different localities is, in round numbers, 23 per cent., the extremes being 19·5 and 28·0.⁷ By carbonization on the large scale in iron vessels heated from without Lampadius obtained a yield from air-dried *Pinus picea*, of about 27 per cent. in weight.⁸ The Author is indebted to his friend and former student Mr. C. B. Hambly, who was engaged some years ago in the manufacture of pyroligneous acid, for the following information on this subject:—The wood used consisted of three-fourths oak and one-fourth of mixed beech, ash, etc., and the distillation was effected in iron retorts 3 feet 6 inches wide and 5 feet long. The yield in weight varied from 25 to 27 per cent.; it was deduced from the distillation of 328 tons 6 cwt. of wood.

EFFECT OF RAPID AND SLOW CHARRING ON THE YIELD OF CHARCOAL.

Numerous experiments by Karsten have proved that the more slowly charring is effected, the greater will be the yield of charcoal. The following table contains his results:⁹—

TABLE SHOWING THE EFFECT OF RAPID AND SLOW CARBONIZATION ON THE YIELD OF CHARCOAL.

| Percentage yield, by weight, of Charcoal from the following Kinds of Wood. | By rapid Charring. | By slow Charring. |
|--|--------------------|-------------------|
| Young oak..... | 16·54 | 25·60 |
| Old do..... | 15·91 | 25·71 |
| Young beech (<i>Fagus sylvatica</i>)..... | 14·875 | 25·875 |
| Old do..... | 14·15 | 26·15 |
| Young hornbeam (<i>Carpinus Betulus</i>)..... | 13·12 | 25·22 |
| Old do..... | 13·65 | 26·45 |

³ *Traitement direct des Minerais de Fer*, p. 174. The weighings were made by François himself. Other results of carbonization will be found in the same volume.

⁴ Valerius, *Traité théorique et pratique de la Fabrication de la Fonte*, etc., 1851, p. 232.

⁵ *Anleitung zur Verkohlung des Holzes*, translated from the Swedish of

Af Uhr, by Blumhof; see Table 1 at the end.

⁶ Karsten, *Handbuch der Eisenhüttenkunde*, part 2, p. 236.

⁷ Scheerer, *Lehrbuch der Metallurgie*, i. 236.

⁸ *Grundriss einer allgemeinen Hüttenkunde*, 1827, p. 48.

⁹ *System der Metallurgie*, iii. 34.

TABLE SHOWING THE EFFECT OF RAPID AND SLOW CARBONIZATION ON THE YIELD OF CHARCOAL—continued.

| Percentage yield, by weight, of Charcoal from the following Kinds of Wood. | By rapid Charring. | By slow Charring. |
|--|--------------------|-------------------|
| Young alder (<i>Alnus glutinosa</i>) | 14.45 | 25.65 |
| Old do. | 15.30 | 25.65 |
| Young birch | 13.05 | 25.05 |
| Old do. | 12.20 | 24.70 |
| Birch of a post which had stood over a grave above 100 years, and was yet sound..... | 12.15 | 25.10 |
| Young silver fir (<i>Pinus picea</i>) | 14.25 | 25.25 |
| Old do. | 14.05 | 25.00 |
| Young spruce fir (<i>Abies excelsa</i>)..... | 16.225 | 27.725 |
| Old do. | 15.35 | 24.75 |
| Young Scotch fir (<i>Pinus sylvestris</i>) | 15.52 | 26.07 |
| Old do. | 13.75 | 25.95 |
| Lime (<i>Tilia Europea</i>)..... | 13.33 | 24.60 |
| Rye straw | 13.40 | 24.60 |
| Dried fern | 17.00 | 27.95 |
| Reeds | 14.65 | 26.45 |
| Mean yield per cent. | 14.42 | 25.69 |

The wood operated upon in these experiments had been previously well air-dried. Karsten's results have been confirmed by Violette,¹ who found that wood dried at 150° C., and afterwards gradually heated to a temperature of not less than 432° C., yielded 18.87 per cent. of charcoal and 81.13 per cent. of volatile matter, whilst the same wood, rapidly heated to the same temperature,² yielded only 8.96 per cent. of charcoal and as much as 91.04 per cent. of volatile matter. Ebelmen has determined the effect of rapid carbonization upon *green* and *dry* wood respectively.³ His conclusion is that, under these circumstances, the yield of charcoal from *dry* wood, as compared with *green*, is in excess proportionate to the degree of desiccation. Ebelmen also found that when different weights of the same wood, in the same state of desiccation, are exposed to a constant temperature in vessels of the same nature and of the same capacity, the proportion of charcoal obtained increases up to a certain limit with the weight of wood operated upon. It has recently been announced by Dromart, a French civil engineer whose name has been already mentioned in these pages, "that the yield of charcoal increases in proportion to the rapidity of carbonization," an announcement which will certainly not be received in opposition to the results above recorded.⁴

ILLUSTRATIVE RESULTS OF CHARCOAL-BURNING IN CIRCULAR PILES.

The following table has been compiled by Beschoren from actual results.⁵ In the first column the yield is estimated by weight; in the

¹ Ann. de Chim. et de Phys. s. 3, 1851, xxxii. 315.

² Idem, p. 314.

³ Recueil des Travaux scientifiques, ii. 178.

⁴ Dingler's Polytechnisches Journal, 1867, clxxxvi. 54.

⁵ Versuche über das Ausbringen an Holzkohlen aus verschiedenen Holzsorten. Bergwerksfreund, iii. 11.

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second column it is stated according to the method of computation by measure first described; and in the third column it is stated according to the second method of computation (see p. 397).

TABLE SHOWING THE YIELD OF CHARCOAL FROM VARIOUS KINDS OF WOOD BY CHARRING IN CIRCULAR PILES.

| No. | Kind of Wood from which the Charcoal was produced. | Yield of Charcoal. | | |
|-----|--|---|---|---|
| | | Number of parts by weight from 100 parts by weight of Wood. | Number of cubic feet in <i>apparent</i> volume from 100 cubic feet of Wood in <i>apparent</i> volume. | Number of cubic feet in <i>apparent</i> volume from 100 cubic feet of Wood in <i>actual</i> volume. |
| 1 | Oak | 21·302 | 71·842 | 98·678 |
| 2 | Do..... | 23·447 | 74·299 | 102·009 |
| 3 | Beech | 22·661 | 78·029 | 100·369 |
| 4 | Birch | 20·945 | 68·518 | 94·189 |
| 5 | Hornbeam | 20·575 | 57·197 | 78·584 |
| 6 | Scotch fir (<i>Kiefer</i>) | 25·029 | 63·561 | 87·157 |
| | Mean | 22·355 | 68·195 | 98·645 |

The charring was effected in circular piles in which the wood was stacked vertically, in either two or three layers; and all the observations seem to have been made with great care at Eisleben, under the immediate direction of Beschoren, who styles himself a charcoal-manufacturer. The ages of the trees from the wood of which the charcoal was produced were as follow:—the oak and beech from 150 to 200 years, the birch and hornbeam from 50 to 60 years, and the fir from 70 to 80 years.

The following summary of the actual results obtained by Beschoren may be interesting in a practical point of view, as showing the time required to effect the charring of given quantities of wood in circular piles. The numbers in the first column correspond to those in the first column of the last table, in which the kind of wood operated upon may be seen:—

TABLE SHOWING THE TIME REQUIRED TO CARBONIZE GIVEN WEIGHTS OF WOOD IN CIRCULAR PILES, AND THE WEIGHTS OF CHARCOAL PRODUCED.

| No. | When lighted. | When cooled. | Duration of charring process, in Days. | Weights in Pounds Prussian.* | | | |
|-----|---------------|--------------|--|------------------------------|--|--|---------------------|
| | | | | Weight of Wood used. | Wood consumed in filling the Pile from time to time, to be deducted. | Actual Weight of Wood from which the Charcoal was derived. | Weight of Charcoal. |
| 1 | Sept. 4 | Sept. 16 | 13 | 68,035 | 120 | 67,915 | 14,467 |
| 2 | " 7 | " 20 | 14 | 67,595 | 205 | 67,390 | 15,801 |
| 3 | " 1 | " 12 | 12 | 47,685 | 102 | 47,583 | 10,783 |
| 4 | Aug. 30 | " 12 | 14 | 47,680 | .. | 47,680 | 9,976 |
| 5 | " 7 | Aug. 17 | 11 | 52,470 | 80 | 52,390 | 10,780 |
| 6 | Sept. 27 | Oct. 15 | 19 | 55,660 | 1983* | 53,677 | 13,435 |

* This includes a considerable amount of brands, i.e. imperfectly carbonised pieces.

* 1 pound Prussian = 1·031 pound avoirdupois.

The weather was unfavourable during the charring of No. 6, and too much air entered the pile, owing to the dryness of the ground: the large yield is to be explained by the fact that the wood was much drier than that charred in the preceding experiments. In No. 5 the wood was not nearly so dry as in the first four experiments. The *apparent* volume of wood operated on ranged from 1149 to 2025 cubic feet (Prussian), and the *actual* volume from 836.02 to 1476.77 cubic feet.

RESULTS OF CHARCOAL-BURNING IN CIRCULAR PILES AT THE HOROWITZ IRONWORKS, IN BOHEMIA, IN 1865 AND 1866.—A series of experiments was systematically conducted at these works in the years stated, in order to ascertain the influence of the nature, age, and place of growth of wood, as well as that of quicker and slower carbonization, upon the yield of charcoal. Charring was effected in the circular pile (*Meiler*) with the wood stacked more or less vertically; and charcoal instead of wood was supplied to the central chimney in order to keep up combustion for some time after ignition. Well-grown air-dried wood of Scotch fir yielded 18 per cent. less charcoal by volume than spruce and silver fir; but the charcoal from the former was 29 per cent. denser (*schwerer*) than that from the latter. Green wood of silver fir yielded 16 per cent. less by volume than the same wood air-dried; but the charcoal from the former was 10 per cent. denser than that from the latter. Wood grown on light marshy ground yielded 10 per cent. less charcoal by volume than wood of the same kind and age grown on heavy (?) sandy ground (*schweren Sandboden*). When charring took place on sites not previously dried, the yield of charcoal by volume was from 3 to 5 per cent. less than from similar piles on dried sites. By steeply inclining the wood in the pile, 9 per cent. more charcoal by volume was produced, but the weight was about 10 per cent. less than that of charcoal from piles with the wood inclined at an angle of 45° . The best and most uniform results with respect to yield and quality were obtained in piles of from 30 to 35 Klaftern in volume (1 Klafter of wood = $6' \times 6' \times 2\frac{1}{2}' = 90$ cubic feet, — 1 Klafter linear = 6 Vienna feet, — 100 Vienna feet = 103.710 English feet). In larger piles, up to 50 Klaftern in volume, the yield of charcoal was reduced about 4 or 5 per cent. in weight, and there was an increase of about 1 or 2 per cent. in the weight of the small charcoal or breeze, which was greater still when older wood was charred. Accepting the truth of the statement that the longer the charcoal after its formation remains in the pile the greater is the loss, it was decided to modify the process of charring, by conducting the fire slowly to the lowest part of the pile, and then quickly completing what has been designated the third stage (*Zubrennen*, see p. 384). After the adoption of this plan, a yield of 60.7 per cent. by volume and 25 per cent. by weight of the wood was obtained. In 1869 a comparative trial under similar conditions was made with unbarked and barked wood, when it was found that the yield by volume in the case of the barked wood was 17 per cent. greater than in the case of the unbarked; but, on the contrary, the charcoal

from the latter was 12·2 per cent. denser than that from the former. Hence, it is suggested that when the densest charcoal is required, it should be made from unbarked wood.⁷

COST OF CHARCOAL-BURNING AND OF CHARCOAL.

The cost of charcoal will obviously vary with local circumstances, such as the price of wood, rate of wages, facility and distance of conveyance. By way of illustration I insert the following details regarding the cost of the wood used, and of charring in circular piles: the cost of charring in rectangular piles is slightly greater.

COST IN SWEDEN.—Charring was conducted in circular piles at the well-known ironworks and gun-foundry at Finspong, in Sweden. The information has been kindly supplied by the manager of the forests through Andreas Grill (July, 1861). All the labour is contracted for, and is arranged under the three following heads:—

| | s. | d. |
|---|----------|-----------|
| Felling, chopping off the branches, and preparing the wood, | 0 | 6½ |
| per 100 Swedish cubic feet of charcoal..... | | |
| Conveying the wood to charring place, by horse-labour ... | 0 | 6½ |
| Piling the wood, covering the pile, charring and quenching | 1 | 1½ |
| or damping | | |
| Total cost of labour..... | 2 | 2½ |
| Ditto per 100 cub. ft. English * | 2 | 4½ |

A man is calculated to earn from 11d. to 1s. per day; and a horse with driver 2s. 6d. per day.

COST IN FRANCE.—According to François, the cost of 100 kilogr. of beech-wood charcoal in the forest in the Ariège, French Pyrenees, between the years 1835 and 1837, was 5·41 francs. Charring was conducted in circular piles, with the wood stacked more or less vertically. The items are as follow: ⁸—

| | France. |
|--|-------------|
| 1·315 stère of wood at 2·20 fr. per stère (= 1 cubic metre)..... | 2·90 |
| Felling and charring in piles | 2·51 |
| | 5·41 |

In the Ariège, from 1807 to 1842, the price of charcoal in the forest ranged from 4·72 to 5·86 francs per 100 kilogr., and delivered at the forges from 7·56 to 9·96 francs per 100 kilogr.; while, during the same period, the average price of wood in the forest for charcoal-burning ranged from 2·80 to 3·63 francs per stère.¹

The data respecting consumption of wood and yield of charcoal in this locality have been stated on p. 400 of this volume.

⁷ Die Köhlerei bei den Horowitzzer Eisenwerken und deren Resultate in der Periode 1855 bis 1870. Berg- und hüttenmännische Zeitung, 1871, p. 267.

* 108 cub. ft. Swedish = 100 cub. ft.

English.

⁸ Traitement direct des Minerais de Fer, p. 174.

¹ François, idem, p. 176.

COST IN BOHEMIA.—The proportions between the various items of the cost of producing charcoal in a forest in Bohemia, near the Horowitz Ironworks, in each year from 1855 to 1870 inclusive, have recently been published.² Carbonization was effected in circular piles, in which the wood was stacked more or less vertically, and charcoal, instead of wood, was supplied to the central chimney (*Quandel*). Taking the total cost as 100, the average cost for each item is as follows:—

| | Per cent. |
|--|--------------|
| I. Cost of wood | 75·42 |
| II. Wages of charcoal-burners | 10·39 |
| III. Cost of preparing bed for the piles, screening from the weather, etc. | 0·98 |
| IV. Cost of carriage | 11·78 |
| V. Cost of the "cover-work," i. e. preparing and maintaining the cover | 1·48 |
| | <hr/> 100·00 |

The maximum and minimum cost of each item were as under:—

| | |
|--------------------------------------|--------------------------------------|
| I. 79·44 in 1863, and 68·00 in 1859. | IV. 15·00 in 1868, and 9·24 in 1863. |
| II. 17·50 in 1859, and 8·52 in 1865. | V. 1·96 in 1858, and 0·5 in 1857. |
| III. 3·23 in 1859, and 0·47 in 1870. | |

During the period above mentioned the average percentage yield by volume of large charcoal (*Grosskohle*) was 84·65, and of small charcoal (*Kleinkohle*) 15·35; and the maximum and minimum of each kind were 87·14 and 83·00, and 17·00 and 12·86, respectively.³ The wood from which the charcoal was made consisted on the average of 2·8 per cent. by volume of hard wood (in the proportion of about 48 per cent. of beech, 34 of birch, and 18 of oak), 71·10 of silver and spruce fir (*Fichte* and *Tanne*), and 26·10 of Scotch fir (*Kiefer*) and larch. The average yield of charcoal per Klafter (6' × 6' × 2½' Austrian, 100 of which feet = 103·710 English feet) was, during the same period (from 1855 to 1870 inclusive), 44·64 cubic feet of large and 8·04 of small; or 11·16 and 2·01 Tonnen (1 Tonne = 4 cubic feet). The wood was in the form of billets (*Scheitholz*), faggots (*Prügel*), branches (*Astholz*), and stumps (*Stockholz*); and was derived not only from living trees regularly felled (*Holz aus offenen Schlägen*), but from the thinnings of the forest (*Durchforstungsholz*).

SUMMARY OF PRACTICAL DIRECTIONS FOR CHARCOAL-BURNING.

The wood should be of mature growth, neither too old nor too young. It should be felled when most free from sap, that is, during winter. It should be partially or wholly barked and air-dried for some months before burning. According to various writers on the subject, experience teaches that the best result is obtained when the wood is moderately dry: if too dry, the combustion is too quick and not easily regulated by the charcoal-burner, carbonization proceeds

² Berg- und hüttenmännische Zeitung, 1871, p. 270.

³ Compare, however, the article on the | Yield of Charcoal, and the results given in the Table p. 399, which refer to this locality.

irregularly, charcoal is uselessly consumed, and as a consequence its quality is injured and the yield diminished. Svedelius, however, remarks, that if the ground on which the pile rests is dry, solid and impervious to air, and the charcoal-burner is intelligent and careful, the driest wood will give the largest yield and best charcoal. In the case of very dry wood the pile must be as flat as practicable, and the cover must be made thicker and more dense, so as sufficiently to reduce the supply of air to the pile. If, on the other hand, the wood is too moist, the process is considerably prolonged, more care and labour are required, but the charcoal produced is stated to be sounder and of better quality than in the first case. The steam must be allowed freely to escape, by either partially removing the cover, or diminishing its thickness and solidity at the upper part during the sweating stage.⁴ Rotten and worm-eaten wood should be avoided, as the charcoal from it is so bad as to be unfit for smelting. By long exposure to the action of water, whether by floating down rivers or remaining unprotected from heavy rains, wood is sensibly deteriorated for charcoal-burning. Immersion, however, during ten days or a fortnight occasions no injurious effect.⁵ If the ground on which the bed is made is too porous, too much air may find its way into the interior, and so cause unnecessary waste of charcoal. In this case the bed should be rendered less pervious to air by making it more solid; and when practicable, by covering it with a layer of the residual charcoal-dust from previous burnings. A clayey ground is bad, as it may become fissured by the heat evolved in the process; and the fissures may serve as channels for the admission of air, when the same evil would occur as in the last case. In moist ground, a foundation of wood covered with soil should be first laid, and on this the pile should be raised. If a sheltered situation cannot be found, the pile must be protected from wind by hurdles or other suitable expedients. Exposure to wind will obviously tend to prevent regularity in burning. Any hollow spaces caused by the burning away of the fuel used in lighting the pile should be replenished with wood or charcoal or the imperfectly charred pieces from previous burnings, or a mixture of them, and should be pressed well in by means of a pole; and the surface of the pile should be sounded from time to time, to ascertain if hollows exist. Any fissures which may appear in the cover should be stopped. There is nothing fixed in respect to the dimensions of piles; they vary in diameter from 10 feet to 50 and upwards. Most frequently the diameter is from 20 to 30 feet. In height they vary from $\frac{1}{3}$ to $\frac{1}{2}$ of the diameter measured at the base.⁶

Charcoal, it is stated, should not be used in blast-furnaces or forges immediately after burning, as it has been found to improve by keeping at least during several months. With the same charge of ore and flux in an iron-smelting furnace, the same quantity of freshly-burnt char-

⁴ Helmes, Erdmann's Journal für praktische Chemie, 1829, iv. 230.

⁵ Anleitung zur Verkohlung des Holzes, translated from the Swedish of

Af Uhr, by Blumhof, p. 11.

⁶ Scheerer, Lehrbuch der Metallurgie i. 221.

coal was found to be less effective than charcoal which had been kept during two years well under cover.⁷ The workmen, as well as the masters, of the Catalan forges in the French Pyrenees held the opinion that it was desirable to leave charcoal at rest for a while, even in a slightly damp place, from the belief that after such treatment it supports the blast better and is less quickly consumed, and, according to some forge-masters, produces a greater practical result. It is stated that, while tender and light charcoal bears transport better (*i. e.* produces less waste or small charcoal) than that derived from heavy woods, the reverse is the case in the store-house. The charcoal in contact with walls or the ground may absorb saline matter therefrom, and become deteriorated in consequence. The waste of charcoal in the store-house from this and other causes is very variable, and has been estimated at from $\frac{1}{12}$ to $\frac{1}{3}$.⁸ I am at a loss to explain why the quality of charcoal should be improved by keeping.

IMPERFECTLY CHARRED WOOD, OR BROWN CHARCOAL.

The ancient and common method of charring in piles or stacks has been considered by some metallurgists unnecessarily wasteful, on the ground that about half the carbon of the wood is dissipated in the volatile products; and hence the question has arisen, whether it might not be more economical to use imperfectly charred wood, instead of ordinary black charcoal. The practical solution of this question has been attempted chiefly in France, and various papers on the subject, containing reports of trials on a large scale, have been published in the 'Annales des Mines.' Brown charcoal has a deep-brown colour, and, as previously stated, is designated by the French *charbon roux*.

Sauvage reports that in 1836 apparatus was constructed over the mouths of blast-furnaces at ironworks in the north of France, near Sedan, for charring wood in closed rectangular chambers, formed of cast-iron plates set in brickwork, and heated by the hot waste-gas escaping from the furnaces; and not only was the sensible heat of the gas so utilized, but the combustion of the carbonic oxide contained in it was effected by the admission of atmospheric air. The wood previously to charring was cut into small billets. Although the waste of that portion of the wood which in ordinary piles must [it is assumed] be burned in order to develop sufficient heat to char the remainder was by this means avoided, yet a new item of cost was introduced, namely, that of the carriage of the matter which would have been volatilized in the forest if the charring had been conducted there, and which, roundly, may be estimated at

⁷ Karsten, System der Metallurgie, iii. 45.

⁸ François, Traitement direct des Minerais de Fer, p. 179.

$\frac{1}{2}$ of the total weight of the wood in the case of black charcoal, and about $\frac{3}{4}$ in that of brown charcoal. A charge of wood for each carbonizing chamber was 217 kilogr., and its conversion into brown charcoal required about 5 hours, the yield being 115 kilogr. At one furnace there were eight such chambers. After the completion of the process, the contents of a chamber were put into a cubical cast-iron box, provided with a lid, and there left to become extinguished. Occasionally ignition occurred, when a little water was thrown in to quench the charcoal. The charcoal was superficially black and shining; but within was coffee- or tobacco-coloured. The degree of charring was not uniform throughout; for there was some black charcoal, and at the upper part of the chamber the wood seemed to be scarcely more than perfectly dried. In the production of 1000 kilogr. of grey foundry pig-iron, with cold-blast, were consumed 1530 kilogr. of black charcoal (corresponding to 23.32 stères of wood—1 stère = 1 cubic metre), or else a mixture of 697 kilogr. of black charcoal (corresponding to 10.57 stères of wood) and 1942 kilogr. of brown charcoal (corresponding to 8.46 stères of wood). With black charcoal the time required to smelt 1000 kilogr. of the pig-iron was 10.95 hours, and the flux was 127 kilogr.; but with the mixture of the two kinds of charcoal, the time was 9.37 hours and the flux 117 kilogr. Moreover, it is asserted that the yield of pig-iron was 32 per cent. of the ore in the former case and 34 per cent. in the latter. These results were obtained under similar conditions with respect to ore, flux, and furnace. Assuming the preceding data to be accurate, it would appear that the use of the mixed charcoals caused a saving of 4.29 stères of wood per 1000 kilogr. of pig-iron. The scanty results, however, above given are far from sufficient to lead to any trustworthy conclusion on the subject.⁹

Guenyveau, formerly Professor of Metallurgy at the École des Mines, Paris, reports that, in several ironworks which he visited, very good metallurgical results were obtained by the use of what he designates semi-carbonized wood, and that in others the results were not equally satisfactory, though no reason could be assigned for this difference. He states further that at the ironworks near Sedan, where Sauvage made his observations, by using this fuel to the extent of $\frac{3}{4}$ in volume, the working of the furnace was better and more regular, and there was a saving of $\frac{1}{4}$ of the wood consumed when the fuel consisted wholly of common black charcoal. From these results and others obtained at the works of Montblainville, he inferred

⁹ Mémoire sur la Substitution dans les Hauts fourneaux du Bois en partie carbonisé au Charbon préparé en meule dans les Forêts; par M. Sauvage, Elève-Ingenieur des Mines. Ann. des Mines, s. 3, 1837, xi. 527 et seq. Engravings to scale of the apparatus for carbonization accompany this paper; but I do not consider them of sufficient importance to be introduced into this volume. See also a Note sur la Fabrication du

Charbon roux en meules, par M. E. Gueymard, Ingenieur en chef des Mines, Ann. des Mines, s. 3, 1838, xiii. 487; and in the same volume, p. 595, Notice sur la Fabrication du Charbon roux, par M. Gruner, Ingenieur des Mines, in which he suggests that the rectangular pile might be more suitable for the production of this kind of charcoal than the circular one.

that $\frac{1}{3}$ of the wood might be saved by the use of brown charcoal exclusively. But, after having thus reported, Guenyveau adds that he was assured that the advantage derived from the use of brown charcoal was proportionate to the degree of charring, or, what is the same thing, to its approximation to black charcoal in composition and quality; and instead of heating the wood during 4 or 5 hours it was found necessary to continue the process during 10 hours. Moreover, he remarks that it had been the practice to reject, as unfitted for blast-furnaces, any of the charcoal found to be imperfectly charred in circular piles.¹

ECHEMENT'S PROCESS OF MAKING BROWN CHARCOAL.

About the year 1839 a Belgian named Echement announced that he had invented a simple and economical method of making brown charcoal in piles, one of which is represented in the accompanying woodcuts, figs. 60–62. This invention was carried into operation in the woods of Chéhéry, in the Ardennes, and was inspected and described by Sauvage.² A rectangular bed is prepared, which is

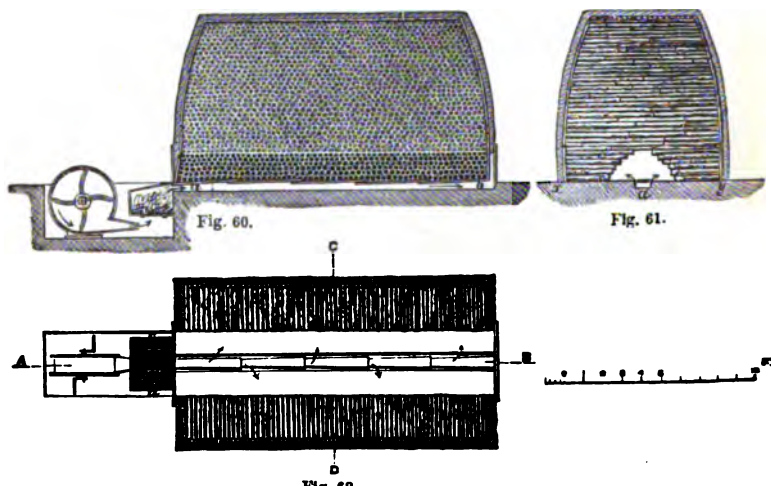


Fig. 62.

Echement's pile for making brown charcoal.

Fig. 60. Longitudinal vertical section on the line *a b*, fig. 62.

Fig. 61. Transverse vertical section on the line *c d*, fig. 62.

Fig. 62. Plan.

bisected longitudinally by a little trench, *a b*, fig. 60, about 0·2 square metre in cross section. Each side of the bed inclines slightly inwards. The trench is covered with cast-iron plates, so fixed as to leave a narrow space a few millimetres wide along their lateral edges, through which space any gases of combustion driven into the trench at one end, may escape from both sides of it throughout its whole length. In front, at one end of the bed, there is a cavity, *c d*, fig. 62, in which a few bars are fixed to form a fireplace. The

¹ Ann. des Mines, s. 3, 1837, xii. 320.

² Idem, s. 3, 1839, xvi. 659.

wood to be charred is stacked with care horizontally and at right angles to the trench, *a b*, above which, from end to end, an arched space from 50 to 60 centimetres in radius is left. In order to render the surface of the pile even, it is covered first with branch-wood, placed in an inclined position, and then with soil and moss, taking care to provide outlets from top to bottom. This done, the fireplace, *f*, fig. 60, is closed with a cast-iron plate in such a way that all the gases evolved from the fuel burnt on the grate may pass thence into the trench, *a b*. The arched space is closed at each end with a cast-iron plate luted with earth. By means of a small wooden fan, capable of being worked by a child, a current of air is forced under the grate, on which a fire is kept up with small bits of waste-wood, branches, and twigs. All the gaseous products of combustion, along with the nitrogen of the air heated in the fireplace, are driven into the trench, whence they escape from each side of it and are distributed through the overlying mass of wood: thus, it will be observed that, in the mode of applying heat, Dromart's process, which has already been described (see pp. 373-77), is essentially similar to Echement's. When the disengagement of the vapour emitted at first from the whole of the pile has slackened, the cover of the latter is made compact and impervious to air, beginning at the top and gradually descending; by which means the height to which the gases rise in the pile is proportionately diminished. Uniformity in the product of carbonization is said to be so attained. The temperature may be increased at will in any part of the pile by making vents in that part; for the current of hot gases driven in by the fan can only pass through the wood where outlets are provided for their escape. With the use of a long hook, and by unstopping the anterior part of the arch, the plates covering the ditch may be raised more or less, and, consequently, the outlet for the gases increased or diminished at will in any part of the trench. By this process, 30 stères of wood may be charred in 24 hours, with a consumption of about 3 stères in the fireplace, or $\frac{1}{10}$ of the wood charred. In the operation, which Sauvage witnessed, the wood was uniformly rendered brown to the centre, excepting that which touched the ground at the points *x* and *y*, fig. 61, where it was less changed. The wood lost about 43 per cent. in weight, and the product contained 38 per cent. of volatile matter. Sauvage was unable to procure a satisfactory statement of the cost of the process. The duration of the process is stated to be much shorter than that of the ordinary methods of charring.

TORREFIED³ WOOD OR *ROTHHOLZ*.

A company in Mainz at the present time prepares wood for fuel by heating it to a degree sufficient, not only to expel hygroscopic water, but to cause incipient carbonization and change its colour to reddish-

³ I have adopted this word for the sake of distinction; it was long ago applied to starch which had been heated to a degree short of incipient charring.

brown. This product is designated by the Germans *Rothholz*, i.e. red-wood. With respect to practical effect, it is stated to be intermediate between air-dried wood and brown charcoal. It has been examined and described by R. Fresenius, and from his description the following information has been derived.⁴ It is made from beech-wood, and, except in colour, perfectly resembles wood in appearance. It may be split, cut, sawn, rasped, etc.; but it offers less resistance to fracture than the original wood. A freshly-split surface has a uniform shining brown colour, inclining to red-brown; but the outside of the billet is darker in tint. It makes only a slight brown mark on paper, and that not without strong pressure. It is with difficulty moistened by water. Its mean specific gravity, inclusive of pores, is 0.54, whereas that of air-dried beech billets was found to be 0.654. It is very feebly hygroscopic, a piece left suspended over water in a tube for 48 hours at 17° C. having absorbed not more than 1.63 per cent.; and what it absorbs either from moist air, or by immersion in water, it soon loses on subsequent exposure to the air. It is much more easily ignited than the driest beech-wood. Its composition is shown in the following table, in which also, for the sake of comparison, that of air-dried beech-wood is inserted:—

COMPOSITION, PER CENT., OF *Rothholz* AND AIR-DRIED BEECHWOOD.

| | <i>Rothholz.</i> | | Air-dried Beechwood. | |
|--------------|---------------------|-----------------------------|----------------------|----------------------|
| | With Ash and Water. | Exclusive of Ash and Water. | With Ash and Water.* | With Ash and Water.† |
| Carbon | 52.66 | 55.38 | 39.10 | 38.85 |
| Hydrogen ... | 5.78 | 6.08 | 4.90 | 4.82 |
| Oxygen | 36.64‡ | 38.54 | 36.00 | 36.33 |
| Ash | 0.43§ | — | 20.00 | 20.00 |
| Water | 4.49 | — | | |
| | 100.00 | 100.00 | 100.00 | 100.00 |

* Mean of the analyses of Schödlér and Petersen, Chevandier, and Baer; computed by Fresenius.

† By Heintz; No. 29 in the table given at p. 186 of this volume.

‡ With traces of nitrogen.

§ After deduction of carbonic acid.

With respect to the proportion of carbon, this product is intermediate between the two kinds of charcoal which Violette prepared at 220° C. and 230° C., respectively, and differs considerably from what he designated *très-roux*, which was prepared at 270° C. The composition of these three products was as follows:—

COMPOSITION, PER CENT., OF CHARCOAL MADE AT 220° C., 230° C., AND 270° C.

| | At 220° C. | At 230° C. | At 270° C. |
|-------------------------|------------|------------|------------|
| Carbon | 54.57 | 57.15 | 70.45 |
| Hydrogen | 4.15 | 5.51 | 4.64 |
| Oxygen and nitrogen ... | 41.06 | 37.03 | 24.06 |
| Ash | 0.22 | 0.31 | 0.85 |
| | 100.00 | 100.00 | 100.00 |

⁴ Erdmann's Journal für praktische Chemie, 1868, ciii. 86.

⁵ Ann. de Chim. et de Phys., s. 3, 1851, xxxii. 322.

The calorific power of *Rothholz*, calculated by Fresenius, is 4371 (taking the calorific power of carbon = 8080, and that of hydrogen = 34462), or about 33·3 per cent. higher than that of air-dried beech-wood, so that 200 lbs. of the latter will be required in order to develop the same number of thermal units as 150 lbs. of the former. It is asserted that, measure for measure, the price of *Rothholz* and beech-wood is the same; and at Mainz, in 1868, a measure of cut beech-wood, containing 1200 lbs., and the same measure of *Rothholz*, containing 920 lbs., cost 11 florins, inclusive of expense in delivery. In small experiments in a copper vessel in the laboratory, Fresenius found that 30 lbs. of beech-wood and of *Rothholz* evaporated 22 and 40·5 litres of water, respectively, so that for a given quantity of water distilled the cost of the two kinds of fuel was in the proportion of 75 to 53. Fresenius recommends *Rothholz* on the following grounds:—it is easily ignited, and is therefore an excellent material for lighting fires with; it may be conveniently conveyed by railways or otherwise; it may be stored even in cellars without risk of deterioration by decay; and on burning it produces copious flame, and is capable of developing intense heat.

THEORETICAL CONSIDERATIONS RESPECTING THE USE OF BROWN CHARCOAL AND TORREFIED WOOD.

If the soundness of the principles previously enunciated concerning calorific power be admitted, the difference in chemical composition between brown and black charcoal is of itself sufficient to prove that the former has less of such power than the latter. Brown charcoal contains much more oxygen and much less carbon than black, and the whole of the oxygen and the proportion of hydrogen which it requires for its conversion into water may, in respect of the number of units of heat developed in combustion, be *practically* regarded as existing in the state of water; and in the sequel experimental evidence in support of this proposition will be presented. But water in fuel, it is hardly necessary to add, means waste of heat; for it has to be evaporated at the expense of the heat resulting from the combustion of the carbon and disposable hydrogen with which it is associated. As, however, the brown charcoal is used immediately after its preparation, it is free from hygroscopic water, which is generally present in black charcoal to the extent, say, of about 12 per cent.; and this is a point of importance. But black charcoal might be perfectly desiccated before it is used.

With respect to the application of the waste-gas of high blast-furnaces, fed with charcoal, to the preparation of that fuel, the cost of conveyance—from, it may be, a considerable distance to the furnace—of a large quantity of matter, which would have been dissipated in the forest if carbonization had taken place there, would doubtless in general be fatal in an economical point of view. If, however, it were otherwise, the main question would remain, whether in such furnaces it would be more profitable to use brown charcoal than black. Now

in the course of its descent in the furnace, brown charcoal is converted into black, or, in other words, the carbonization of wood, which has been purposely left incomplete, is completed in the furnace. But this can only be done at the expense of the heat contained in the gases ascending from the lower part of the furnace where air is injected; and, consequently, the temperature of those gases will be proportionately reduced in the upper part of the furnace. Such reduction in temperature implies corresponding refrigeration, not only of the fuel, but also of the ore and flux, and may tend seriously to interfere with the process of smelting. The case is precisely analogous with respect to the substitution of raw or imperfectly coked coal for coke. The upper part of a high blast-furnace performs in a measure the same function as a Siemens' regenerator, the principle of which will be fully explained hereafter; and the question in all its bearings will be examined when that of the economy of fuel in such furnaces is considered under the head of Iron-smelting.

The foregoing considerations apply with even more force to Torrefied wood or *Rothholz*, since it approaches more nearly to air-dried wood in composition, and contains a still larger proportion of oxygen than brown charcoal.



Fig. 63. Charcoal-burning in Austria.

From a photograph in the Austrian Department of the London International Exhibition, 1862, which was presented to me by M. Dubocq, one of the associate jurors in Class I., and representative of the Austrian State Railway Company. I have, unfortunately, mislaid the photograph, and do not remember the locality where it was taken.

COKE.

Coke, or, as it is sometimes written, coak, is the solid product of the carbonization of coal, and therefore bears the same relation to coal as common charcoal does to wood. The product of the carbonization of peat is termed indiscriminately peat-charcoal or peat-coke, and should be considered before ordinary or coal-coke, according to the classification of the kinds of fuel which has been presented in this volume. But as it has hitherto been produced only occasionally and in small quantity, and can hardly be said to have come into use, and as, moreover, the principles of the processes employed in the carbonization of coal are essentially the same as in the case of wood, the consideration of peat-charcoal will follow that of coke.

HISTORICAL NOTICE CONCERNING COKE.

The date of the first application of coke as fuel does not appear to have been ascertained. When charcoal became dear, especially on account of the increasing consumption of it in ironworks,¹ and pit-coal was coming into general use, attempts would naturally be made to produce from the latter a substance which might be substituted with advantage for the former; and, obviously, the first experiment would be to subject coal to a process similar to that of charcoal-burning, when coke would be produced, and soon be found valuable as fuel for various purposes.

Until comparatively recent times, coke was always made by burning coal in piles, technically designated "fires"; and even at the present day coking in this manner is extensively practised. It is stated that in March, 1651, Jeremy Buck, by a special Act of Parliament, obtained a patent for making iron with stone-coal, pit-coal, or sea-coal *without charking*.² Hence it may be inferred that the process of coking was known and practised before that date. The verb "chark" means "to burn to a black cinder;" whereas the meaning of "char" is defined to be "to burn wood to a black cinder."³

In Plot's 'History of Staffordshire,' published in 1686, it is recorded that coal was charred in exactly the same manner as wood; and that the coal thus prepared was called "coak," which was

¹ "The yron mills are excellent for that;
I have a patent draune to that effect;
If they goe up, downe goes the goodly trees.
We make them search the earth to find new fire."

—From an old play, by Decker, entitled 'The Oostlie Whore.' London, 1633, B. 4.

² Abridgments of the Specifications relating to the Manufacture of Iron and Steel, 1857, p. 8.

³ Johnson's Dictionary, London, 1805, 9th ed. Longman and Co.

capable of producing almost as strong a heat as charcoal itself. It was used for drying malt, and could generally be employed as a substitute for charcoal, except "for *melting, fineing, and refining* of iron, which," says Plot, "it cannot be brought to doe, though attempted by the most skillfull and curious *artists*." ⁴

Swedenborg, writing in 1734, informs us that in certain districts in England coke was employed in the smelting of iron, and that cinders and coke were synonymous.⁵ In 1769 Jars announced the fact, that coke was made in England, not only in piles, but also in a closed furnace, of which however he did not describe the construction.⁶ The iron-masters of Liège, a short time afterwards, adopted with success that method of coking. At about the same time, according to Horne, coking in ovens was carried on in the villages round London, the coke being prepared for the use of maltsters and for some other purposes. He has given the following description of the process:—"These ovens being from time to time charged with a proper quantity of coals, they set them on fire. Near the front or opening of these ovens the chimneys are placed; at which outlets, when the coals become sufficiently ignited, the flames, which play round the interior parts of the oven, make their exit, carrying along with them a very considerable part of crude sulphur. The workmen employed at these ovens, when they imagine the coals are sufficiently burnt, draw them out with an iron raker upon the ground before the oven, where they endeavour to stifle the yet remaining part of the sulphur by quenching them with a deluge of water. Thus they go on charging, discharging, and suffocating till they have completed their intended quantity."⁷

An experimental coke-oven, on a plan proposed by Horne, was erected in Staffordshire, and, it is stated, with a successful result. The details of the plan are not given. It appears, however, that the oven consisted of a closed arched chamber, and that on trial it was found to be desirable to leave some outlet "in the top of the crown" for the escape of vapour, in order to prevent the blowing-up of the oven. In 1781, according to Bishop Watson, the application of coke to the smelting of iron had become general in this country; and coke-ovens were in operation at Newcastle-on-Tyne, and even at Cambridge, where the coke was used for drying malt.⁸

⁴ The Natural History of Staffordshire; by Robert Plot, LL.D., Keeper of the Ashmolean Museum, and Professor of Chymistry in the University of Oxford; Oxford, 1686, p. 128.

⁵ "Interdum vel aliquibus in locis usurpare volunt carbonēs fossiles, sed qui in cineres aut in cindres (*cinders*) ut vocantur, primum combusti aut calcinati sint."—*Regnum Subterraneum sive Mineralia de Ferro*, etc., Dresdæ et Lipsiæ, folio, 1734, p. 156.

⁶ *Voyages métallurgiques*, Paris, 1774, p. 337.

⁷ Essays concerning Iron and Steel. With an Appendix, discovering a more perfect Method of Charring Pit-Coal, so as to render it a proper Succedaneum for Charred Wood-Coal. By Henry Horne. London, 1773; pp. 205–207.

⁸ Watson's Chemical Essays, 4th edition, ii. 339 et seq. The preface is dated 1781.

GENERAL PROPERTIES OF COKE.

The coke occurring in commerce varies considerably in external characters. Thus, it may be porous and light, or compact and heavy; soft and tender, or hard and resisting; black and dull, or light-grey and bright, almost metallic in lustre: occasionally it is iridescent. It also varies much in degree of combustibility. A kind of coke which is good for one purpose may be bad for another. In certain metallurgical operations coke is required to support considerable pressure without crumbling, while in others it is scarcely exposed to greater pressure than coal in an ordinary fire-place. The quality of coke depends not merely upon the nature of the coal from which it is derived, but also upon the manner in which the process of coking is conducted.

COMPOSITION OF COKE.

Coke consists essentially of carbon and the fixed inorganic matter of the coal from which it has been derived, but contains also hydrogen, nitrogen, and oxygen, and sulphur, in the state of sulphide of iron. The following analyses of coke, which had been previously dried, will suffice for illustration:—

TABLE SHOWING THE PERCENTAGE COMPOSITION OF DRY COKE.

| | I. | | II. | | III. | |
|---------------------|-------------------------------|-------------|-------------------|-------------|-------------------|--------|
| | Exclusive of Sulphur and Ash. | | Exclusive of Ash. | | Exclusive of Ash. | |
| Carbon | 85·84 ... | 97·83 | 91·30 ... | 97·33 | 91·59 ... | 97·33 |
| Hydrogen | 0·52 ... | 0·60 | 0·33 ... | 0·35 | 0·47 ... | 0·50 |
| Oxygen and nitrogen | 1·38 ... | 1·57 | 2·17 ... | 2·32 | 2·05 ... | 2·17 |
| Sulphur | 0·86 ... | — | — ... | — | — ... | — |
| Ash | 11·40 ... | — | 6·20 ... | — | 5·89 ... | — |
| | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 |

I. Coke from the Dukinfield Colliery (see No. 55a of the table on p. 329, *antea*, but it is not known whether this coke was produced from the coal of which the analysis is given). The sample analysed had been dried at or slightly above 100° C. The colour of the ash was buff or light-yellow. The analysis was made in my laboratory in 1864, by C. Tooke.

II. III. The coke was prepared by heating coal of the Mons basin during 48 hours in ovens with flues under their bottoms. The analyses were made by M. de Marsilly, and the specimens operated upon had been dried at 200° C.*

* Ann. des Mines, s. 5, 1857, xli. 400.

WATER IN COKE.

The coke of commerce always contains water, of which the quantity, according to M. de Marsilly, should not exceed 2 or 3 per cent., though occasionally it has been found to amount to 5 or 6 per cent. M. de Marsilly ascertained that perfectly dry coke will not absorb more than from 1 to 2.5 per cent. of water by exposure to an atmosphere saturated with moisture at ordinary temperatures, but that it may, by immersion in water during 24 hours, absorb as much as 51 per cent. of its weight. In eleven experiments by him this was the greatest amount of absorption, and the least was 12.5 per cent., the average being 36.25 per cent. Before immersion, the coke was dried between 100° and 200° C., and weighed; and after its immersion it was taken out of the water, drained, and weighed again. The greater part of the water thus absorbed is soon evaporated when the coke is exposed to the open air. It is scarcely necessary to remark that when coke is required to produce its maximum calorific effect, it should be as dry as possible. When the process of coking is completed, the coke is extinguished by throwing water upon it, and the proportion of water which it retains will depend in a great degree upon the manner in which that operation is performed. If coke-burners be paid according to the weight of coke produced, or if coke be sold by weight, the knowledge of the quantity of water in it may be a matter of commercial importance.

ACTION OF STEAM ON INCANDESCENT COKE.

When steam is passed over red-hot coke, hydrogen, marsh-gas in small proportion, carbonic oxide, and carbonic acid are formed, as will be seen from the results of experiments presented in the following table: the composition of this gaseous mixture has been found to be nearly the same whether the steam passes over a single piece or through a column of incandescent coke.

TABLE SHOWING THE COMPOSITION, PER CENT., BY VOLUME OF THE GASES RESULTING FROM THE ACTION OF STEAM ON RED-HOT COKE.

| | I. | II. |
|----------------------|--------------|---------------|
| Hydrogen | 54.52 | } 56.90 |
| Marsh-gas | 1.62 | |
| Carbonic oxide | 31.86 | |
| Carbonic acid | 12.00 | |
| | <hr/> 100.00 | <hr/> 100.00 |

I. The coke operated upon had been previously heated in a platinum crucible under a layer of sand, in order to expel any matter capable of volatilization which it might contain. A porcelain tube was used in the experiment. The composition was found

by explosion with oxygen in the eudiometer. The analysis was made by Langlois.¹

II. The coke operated upon was made from Derbyshire coal. The analysis was made by Frankland.

Langlois ascertained that in the case of charcoal, when the temperature was raised from a red to a red-white heat, the proportion of carbonic acid was much reduced, and that of the carbonic oxide correspondingly increased (see pp. 364, 365), whence it may be inferred that coke would yield a similar result.

In the preceding analyses no mention is made of sulphuretted hydrogen, resulting from the action of steam on the sulphide of iron which all coke contains. This point will be considered in the sequel in an article on the Desulphurization of Coke.

GENERAL CONSIDERATIONS ON THE PREPARATION OF COKE.

When a mass of coal is put into a common gas-retort previously heated to redness, it is obvious that the portion of it which first comes in contact with the red-hot surface of the retort must be exposed to the highest degree of heat, and that for some time afterwards the temperature will continue proportionately lower towards the centre of the mass; and when a large quantity of coal—say, several tons—is thus heated in a single chamber, a considerable period must elapse before the whole mass can become heated to the same degree. Hence, during that period, the destructive distillation of the coal in different parts will be effected at different temperatures.² But the

¹ Ann. de Chim. et de Phys. s. 3, 1857, li. 322.

² I have received (July 1874) from my former colleague, Dr. Hofmann, now Professor of Chemistry in the University of Berlin, the following revised list of the compounds generated by the destructive distillation of coal:—

| | | |
|---|--|---|
| Hydrogen | H | [idem] |
| Water | HO | [H ² O] |
| Carbonic oxide | CO | [idem] |
| Carbonic acid | CO ² | [idem] |
| Sulphurous acid..... | SO ² | [idem] |
| Hydrosulphuric acid (Sulphuretted Hydrogen) | HS | [H ² S] |
| Bisulphide of carbon | CS ² | [idem] |
| Hydrocyanic acid | HC ² N | [HCN] |
| Hydrosulphocyanic acid | HC ² NS | [HCNS] |
| Acetic acid | C ² H ⁴ O ² | [C ² H ³ O ²] |
| Carbolic acid (Phenol) | C ¹² H ⁸ O ² | [C ⁶ H ⁶ O] |
| Cresylic acid (Cresol) | C ¹⁴ H ¹⁰ O ² | [C ⁷ H ⁸ O] |
| Phlorylic acid (Phlorol) | C ¹⁶ H ¹² O ² | [C ⁸ H ¹⁰ O] |
| Rosolic acid .. | C ²⁰ H ¹⁶ O ² | [C ²⁰ H ¹⁶ O ²] (?) |

HYDRO-CARBONS.

| | | |
|---------------------------|---------------------------------|---|
| Methane (Marsh-gas) | C ² H ⁴ | [CH ⁴] |
| Sextane (Propyl) | C ¹⁸ H ¹⁴ | [C ⁶ H ¹⁴] |
| Octane (Butyl) | C ¹⁶ H ¹² | [C ⁸ H ¹²] |
| Decane (Amyl) | C ²⁰ H ¹⁶ | [C ¹⁰ H ¹⁶] |
| Duodecane (Caproyl)..... | C ²⁴ H ²⁰ | [C ¹² H ²⁰] |
| Paraffin | C ⁿ H ⁿ⁺² | [C ⁿ H ²ⁿ⁺²] (?) |

[Ethene

nature of the products of such distillation varies with the temperature: thus, at low temperatures volatile substances rich in carbon are generated, which at higher temperatures are decomposed with the *deposition of carbon*. When, for example, olefant-gas, which is one of the products of the dry distillation of coal, is passed through a red-hot porcelain tube, it is decomposed with the separation of carbon and the formation chiefly of marsh-gas. Now, in heating a considerable mass of coal in the manner described, the temperature towards the interior may be low enough to generate various highly carbonaceous volatile products, which, on approaching the walls of the chamber where the temperature is higher, will deposit a portion of their carbon; and it is in this manner that the internal surface of gas-retorts acquires in the course of time a solid and firmly adherent coating of carbon of considerable thickness.

Let us suppose coal piled to the thickness of two or three feet in a fire-brick chamber, entirely closed, with the exception of a hole in the

| | |
|-----------------------------|-----------------------------------|
| Ethene (Olefiant-gas) | C^2H^4 [C^2H^4] |
| Tertene (Propylene) | C^3H^6 [C^3H^6] |
| Sextene (Caproylene) | $C^{12}H^{12}$ [C^6H^{12}] |
| Septene (Enanthylene) | $C^{14}H^{14}$ [C^7H^{14}] |
| <hr/> | |
| Ethine (Acetylene) | C^2H^2 [C^2H^2] |
| <hr/> | |
| Benzol | $C^{12}H^6$ [C^6H^6] |
| Toluol | $C^{14}H^8$ [C^7H^8] |
| Xylol | $C^{16}H^{10}$ [C^8H^{10}] |
| Cumol | $C^{18}H^{12}$ [C^9H^{12}] |
| Cymol | $C^{20}H^{14}$ [$C^{10}H^{14}$] |
| <hr/> | |
| Naphthalin | $C^{20}H^8$ [$C^{10}H^8$] |
| <hr/> | |
| Anthracene | $C^{28}H^{10}$ [$C^{14}H^{10}$] |
| Phenanthrene | $C^{28}H^{10}$ [$C^{14}H^{10}$] |
| <hr/> | |
| Fluorene | $C^{30}H^{10}$ [$C^{15}H^{10}$] |
| Pyrene | $C^{32}H^{10}$ [$C^{16}H^{10}$] |
| Chrysene | $C^{36}H^{12}$ [$C^{18}H^{12}$] |

BASIC NITROGEN COMPOUNDS.

| | |
|--------------------|-------------------------------------|
| Ammonia | H^3N [idem] |
| Aniline | $C^{12}H^7N$ [C^6H^7N] |
| <hr/> | |
| Pyridine | $C^{10}H^5N$ [C^5H^5N] |
| Picoline | $C^{12}H^7N$ [C^6H^7N] |
| Lutidine | $C^{14}H^9N$ [C^7H^9N] |
| Collidine | $C^{16}H^{11}N$ [$C^8H^{11}N$] |
| Parvoline | $C^{18}H^{13}N$ [$C^9H^{13}N$] |
| Corindine | $C^{20}H^{15}N$ [$C^{10}H^{15}N$] |
| Rubidine | $C^{22}H^{17}N$ [$C^{11}H^{17}N$] |
| Viridine | $C^{24}H^{19}N$ [$C^{12}H^{19}N$] |
| <hr/> | |
| Chinoleine } | $C^{18}H^9N$ [C^9H^9N] |
| Leucoline } | $C^{20}H^{11}N$ [$C^{10}H^{11}N$] |
| Lepidine | $C^{22}H^{13}N$ [$C^{11}H^{13}N$] |
| Cryptidine | $C^{24}H^{15}N$ [$C^{12}H^{15}N$] |
| <hr/> | |
| Pyrrol | C^4H^5N [C^4H^5N] |

top to act as a chimney, and a few small openings through which air from without may enter *above* the surface of the coal; and let us further suppose, that the whole of the upper part of the coal is burning actively, that air to sustain combustion is entering through the small openings, and that the volatile products of combustion are escaping through the hole in the top. The oven above the coal will speedily be heated to redness, and heat will be propagated downwards through the coal, of which every portion will be successively subjected to destructive distillation. The volatile products from below will ascend through the red-hot overlying stratum of coked coal, and, protecting it from contact with atmospheric air, will prevent it from burning to waste. But as these products have been formed at a much lower temperature than that prevailing in the upper part of the oven, they may be so rich in carbon as to be decomposed in their ascent, and deposit a portion of their carbon upon the coke which they traverse. The deposited carbon is generally bright and almost metallic in lustre; the coked coal will be coated with a deposit of this lustrous carbon, while the more or less decarbonized residual gases will take fire as they escape from the incandescent mass and come into contact with the air, which enters through the small openings above its surface.

INFLUENCE OF TEMPERATURE UPON THE YIELD OF COKE.—From the foregoing considerations it might be inferred that the temperature at which coking is conducted would influence the *yield* of coke, and that *ceteris paribus*, within certain limits, the higher the temperature the greater the yield, an inference of which the truth has been confirmed by experience.

INFLUENCE OF TEMPERATURE AND DURATION OF COKING UPON THE QUALITY OF COKE.—The *quality* of coke, also, is much affected by the temperature at which it was made and the duration of the coking process. It may be stated as a general rule that the higher the temperature, and the longer the exposure to that temperature, the harder, more dense, and less easily combustible will be the coke. M. de Marsilly tried the effect of coking during 96 and 120 hours, but found that no advantage was derived by prolonging the process beyond 48 hours.

DIFFERENCE IN STRUCTURE OF THE COKE PRODUCED FROM CAKING AND NON-CAKING COALS.—When caking coals are coked, they first agglutinate into one mass, which, as the process proceeds, becomes fissured from top to bottom so as to form a series of columnar pieces, resembling the columnar structure which is induced in sandstone by the long-continued action of a high temperature, or the structure which starch acquires by desiccation. To this state of aggregation the term crystallization is frequently, though very erroneously, applied.

The coke from non-caking coal is in lumps, resembling in form those of the coal from which they have been derived, but fissured throughout.

HAIR-LIKE FORM OF COKE.—Hair-like threads are sometimes observed on pieces of coke. They are nearly solid, and under the microscope occasionally present somewhat of the appearance of a string of beads

soldered together. They consist of carbon, which seems to have been deposited in the following manner:—A bubble of tarry or hydrocarbon vapour and gas, in escaping from the surface of the coke, becomes more highly heated, and is in consequence decomposed with the separation of solid carbon, which is deposited as a continuous coherent film on the surface of the bubble; a second bubble escapes through the carbonaceous shell of the first, and is similarly decomposed, forming a second carbonaceous shell attached to that resulting from the first bubble; and so by a succession of such deposits of carbon a continuous tube is formed. Gas would continue to flow through this tube, depositing carbon in its course on the *inner* surface, until at length the tube is converted into a nearly solid fibre. Such appears to me to be the mode of formation of this curious hair-like matter, though I am by no means certain of the correctness of this view. I have noticed considerable variety in appearance in the specimens of hair-like coke, which I have examined under the microscope. This is a subject which deserves investigation by a competent microscopist.

VARIOUS MODES OF COKING.

Coking is conducted in the open air in piles or stacks; in kilns open at the top; or in closed kilns or ovens of brick or stone: in all of which cases carbonization is mainly effected by the heat resulting from the combustion of the volatile products evolved during the process; and the special aim of the coke-burner should be to bring atmospheric air in contact with those gases, and prevent its contact with the coke formed. Coking is also conducted in retorts heated externally, as in the manufacture of coal-gas; but this last method is not within the province of Metallurgy, except in so far as any of the coke-ovens in use may by their construction fulfil the conditions of a retort.

COKING IN PILES.

The terms "coke-hearths" and "coke-fires" are applied synonymously to piles. The piles are either circular or in the form of pyramidal heaps having a long narrow rectangular base. The ground on which they rest should be flat, dry, and solid; and a plentiful supply of water should be at hand. The principle of this mode of coking is similar to that of charcoal-burning in piles or stacks: a considerable quantity of coal is burned to waste, as may be inferred from the layer of ashes covering the entire surface of the pile at the conclusion of the process. It is hardly necessary to add that piles are not suitable for the coking of *slack*.

COKING IN CIRCULAR PILES.

The piles vary considerably in size according to circumstances and the practice of the coke-burner. The annexed woodcut, fig. 64, represents a circular pile such as I used frequently to see between

twenty and thirty years ago at the Russell's Hall Ironworks, near Dudley. The bed was of earth, not of brick. In the centre was a chimney, built of bricks without mortar, which is shown in elevation at *a*, and in plan at *b*. The dark shaded part, *c*, on the left

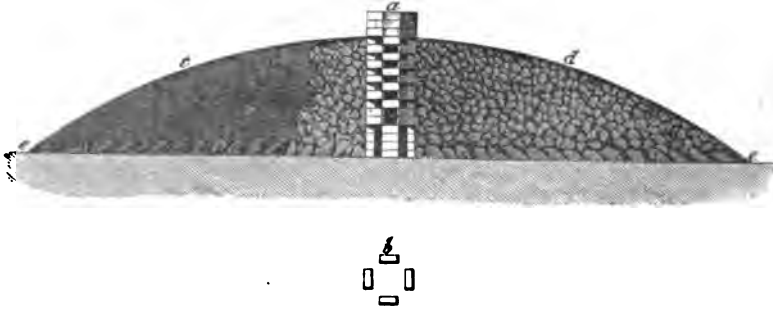


Fig. 64. Circular coke pile at the Russell's Hall Ironworks, near Dudley; partly in elevation, and partly in vertical section. The portion from *e* to *c* and from *e* to *d* is not shown quite steep enough in the engraving.

of the chimney is a view in elevation of that part, the rest of the pile being shown in vertical section through the centre of the bed, with the exception of the chimney, which, as previously stated, is seen in elevation. The diameter at the base of the pile was 30 feet. The height of the pile from the centre of the base to the highest part near the chimney was five feet. Four bricks are first laid as shown at *b*; upon each brick three others are placed, and thus four pillars of four bricks each are formed. Across the ends of these pillars two courses of bricks are laid, and then the chimney is continued upwards by placing the bricks octagonally, so as to leave regular spaces between their ends all round, as shown in fig. 64. The upper part of the chimney, above the top of the pile, is built without spaces. A large flat brick placed on the top of the chimney serves as a damper; or else an apparatus, such as is shown in the annexed woodcut, fig. 65, may be substituted. This apparatus is set on the top of the chimney, and consists of a cylinder of cast-iron, about 14 inches high and $10\frac{1}{2}$ inches in internal diameter, flanged at the bottom, where the internal diameter is reduced to about 8 inches; and of the damper, *a*, which is a disc of iron, provided with an upright handle. The damper is covered over with sand when it is desired to close the chimney perfectly. The heat of the pile is sufficient to vitrify the surface of the bricks of which the chimney is built, and to cause them to stick together.

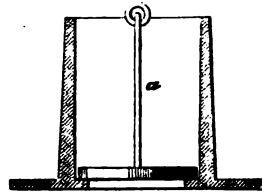


Fig. 65. Vertical section of a damper through the centre.

In some piles the chimney was larger, and rested on six pillars of bricks instead of four. The diameter at the base of a chimney of this kind was 3 ft. 3 in. outside measure; and arch-bricks were employed.

The coal operated upon was the non-caking Ten-yard coal. The large coal is first stacked, round and inclining against the chimney, and then the lumps, *i.e.* smaller coal; when the stacking is completed, the whole surface of the pile is covered with a layer of wet coke-dust from previous burnings, *except round the bottom of the pile, &c., to the height of about a foot.* Ignition is effected by putting live coals on one side of the chimney near the top. Combustion is thus conducted downwards through every part of the mass. Thick smoke speedily appears, and flame issues from the chimney and various parts of the surface. The progress of the coking is carefully watched; where the combustion appears too vigorous, the coker checks it by applying coke-dust. After a time beautiful blue flames of carbonic oxide appear here and there over the surface. When coal smoke ceases to escape, and the process of burning is completed, which will occur in about 5 or 6 days, wet coke-dust is plastered, by means of a spade, over every part of the surface of the pile, including the space round the bottom previously left uncovered, and the chimney is perfectly closed. In windy weather much attention is necessary on the part of the coke-burner to prevent as far as practicable the waste which is liable to occur from the increased combustion in the part exposed to the wind. Numerous precautions are necessary to ensure a successful result, but these can only be learnt by experience. Simple as the process may appear, yet the men who conduct it differ much in their degree of skill. On about the tenth day after lighting the coke may be drawn. Before drawing the pile is watered; that is, water is thrown upon it. In the pile described, about 20 tons of coal (1 ton = 2640 lbs.) were stacked. The yield from such a pile was stated to be $3\frac{1}{2}$ barrows or 13 cwt. to the ton of coals (2640 lbs.); that is, 65 per cent. of the coal.

At the Coalbrook Vale Ironworks, South Wales,² I observed coking in circular piles about 18 feet in diameter at the base and 6 feet high in the centre. Mr. James, the furnace manager, informed me that the pile was lighted at these works by putting live coals down the chimney, and that the coal round the bottom became first ignited, whence the fire creeps towards the outside of the pile round the base, and extends upwards; and in proportion as it rises, the surface of the pile below is damped in the usual way. A column of flame 2 feet high may continue to issue from the chimney during some time after lighting. The chimney is left open till the fire nearly reaches the top, when it is covered with an iron plate.

In Mushet's description of this process,³ it is stated that brick flues, or channels formed by pieces of coal, are laid to communicate with the lower tier of holes in the chimney, so as to conduct the air through the interior of the mass. In other respects his description is similar to that last given. Mushet, however, observes, that, as the fire pro-

² Coalbrook Vale, in the Blaina valley, South Wales, must not be confounded with Coalbrook Dale, in Shropshire—a

mistake which is not unfrequently made.

³ Papers on Iron and Steel, 1840, p. 304.

ceeds upwards, the ignited surface of the exposed coal (which forms a zone never more than 4 or 5 inches broad) is from time to time covered with coke-dust and a new surface exposed above, the dust of which, crumbling and falling down, protects the ignited surface of the recently formed coke below. In this way the fire in 2 or 3 days reaches the upper surface of the pile, when the flame in the chimney becomes less, and afterwards disappears. Mushet further remarks that this process may be modified so as to yield coke of different qualities from the same kind of coal. When the opening round the bottom of the pile is much diminished, the process is retarded, and the fire requires a longer time to reach the outer surface. The yield thus obtained is said to be greater than when the coking takes place more rapidly; the coke being darker, less combustible, with a higher specific gravity, and little changed in form [from the original coal?]. On the other hand, it is stated that when the pile is left open round the base to the height of a foot, combustion proceeds more rapidly on account of the freer access of air; a higher temperature is produced; the coke is honeycombed; is more grey in colour; has a lower specific gravity; is more combustible; and less in quantity.

According to Mushet this system of coking under wetted dust was introduced at the Muirkirk and Clyde Ironworks about the year 1801, and in a few years became general at the Scotch furnaces. In 1805 it was introduced into Derbyshire, and subsequently into Staffordshire, Yorkshire, and Shropshire. He further states that it had been attempted at Merthyr, but without success, as the coal passed "almost unchanged in form into a ponderous coke resembling anthracite;" and at other works in South Wales, in which a caking coal was employed, it was tried and abandoned in consequence of the slow combustion occasioned by the welding of the coal, and the rents and cracks caused upon the surface of the pile by the great enlargement of its volume.⁴ Now it has been shown that in Staffordshire coking in piles was commonly practised long anterior to 1805; but Mushet probably means to intimate that a covering of "wetted dust" had not been previously applied. In times anterior to that date the pile seems to have been constructed exactly like a charcoal pile, and to have been covered with straw, leaves, and soil in succession.⁵

COKING IN LONG PILES.

These piles, which are sometimes termed "pits" (like *lucus a non lucendo*), may be extended to any length, and may be conveniently arranged in parallel rows. At the Coalbrook Vale Ironworks, I measured one, of which the transverse section at the base was 12 feet, and the height in the centre 3 ft. 6 in. A pile of these dimensions will contain from 2 tons 10 cwt. to 3 tons per linear yard. The late Mr. Levick, one of the proprietors of the works, informed me that

⁴ Papers on Iron and Steel, 1840, p. 304. | du Coke, etc.; par M. Pelouze, père;
⁵ Traité méthodique de la Fabrication | Paris, 1842, p. 9.

they vary from 4 to 5 feet in height in the centre, and from 9 to 12 feet in width at the base. There are no chimneys as in the circular piles. A layer of small coal, from 12 to 16 inches thick, is placed at the bottom; and upon this the large coal is stacked, inclining towards the middle of the ridge, and in such a manner as to leave air-passages all through the inside of the pile; the outside is covered with a layer of small coal. The pile is lighted at short intervals along the top, and the combustion is conducted downwards. As the flame ascends up the outsides of the pile, the coker continues to damp them with wet coke-dust until the coal is completely coked throughout; when this occurs, the pile is well plastered over with wet coke-dust, and then left to itself. Before the fire is quite extinguished, the pile is watered and the coke drawn as required. I have seen this method of coking largely practised at Cyfarthfa, Lowmoor, and elsewhere.

COKING IN LARGE OPEN RECTANGULAR KILNS.

A description of this method, as practised at Gleiwitz, in Upper Silesia, was published in 1851 by Brand,⁶ manager of the ironworks there, who states that it had been previously in operation in the principality of Schaumburg-Lippe, where a pure but very tender and strongly caking coal is raised. According to Brand, who wrote from personal experience of the subject, the advantages of this method are, that it requires only a very moderate outlay, and produces a dense coke of excellent quality.

The kiln, which is shown in the accompanying woodcuts, figs. 66, 67, and 68, consists of two parallel walls of brick, *a a*, fig. 67, and a flat bed of bricks set edgewise, *b*, underneath which is a stratum of a glassy blast-furnace slag broken small, so that proper drainage may be secured. Fire-bricks are only used to form the bed and the inner surface of the walls; the walls are 5 feet high, 8 feet apart in the clear, and from 44 to 60 feet long (Prussian measure). In each wall is a series of transverse openings, *c c*, etc., at a distance of two feet from each other, and at the same height above the ground, so that the openings in one wall are respectively opposite to those in the other. From each of these openings, *c*, rises a vertical chimney, *d*. The charging of the kiln is effected as follows:—The space, *e*, between the two walls at one end of the kiln is bricked up, and through the opposite end coal-slack is wheeled in, spread over the bottom, watered, and stamped down so as to form a solid stratum nine inches thick, or as high as the lower edges of the openings, *c c*, etc.; indeed, this height may be made two feet with advantage, if the coal be suitable. Pieces of wood, six inches in diameter at one end, and four at the other, and in length equal to the width of the kiln, are then passed through the openings in one wall so that their opposite ends may respectively lie in the corresponding

⁶ Berg- und hüttenmännische Zeitung, 1851, x. 217.

openings in the other wall. Wetted coal-slack is spread over the pieces of wood, and stamped carefully down. The kiln is then filled up with slack, which at every six inches of additional height should be watered and stamped down. Brand well remarks that the mode of filling just described is very hard work when the kiln exceeds 40 feet in length. After the filling is completed, the top of the coal is covered with a layer, two or three inches thick, of coal-dust; or, failing this, of loam. The end opening through which the

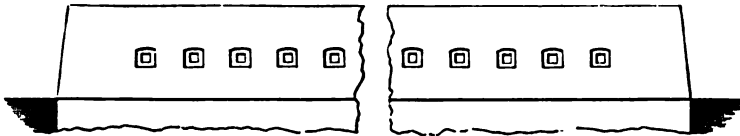


Fig. 66. Side elevation of Silesian coke-kiln.

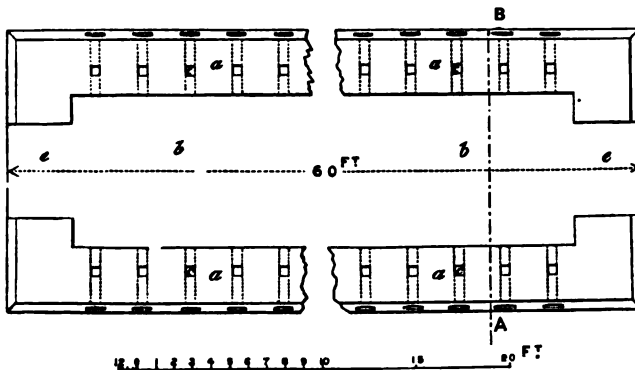


Fig. 67. Plan of Silesian coke-kiln.

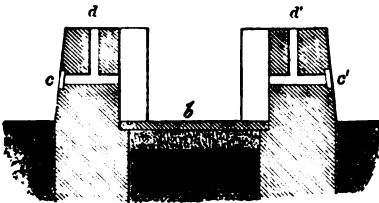


Fig. 68. Transverse vertical section of Silesian coke-kiln on the line A B, fig. 67.

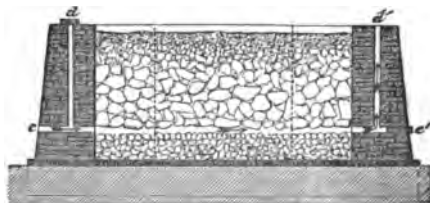


Fig. 69. Transverse vertical section of coke-kiln after filling, designed by the late Mr. E. Rogers, of Abercarn.

kiln has been charged is at last bricked up. The pieces of wood are now carefully drawn out, and thus a series of channels are left in the coal, upon the maintenance of which the success of the process essentially depends. Should an injury occur to any of the channels at the commencement, it can hardly be repaired afterwards. Before lighting the kiln, all the chimneys on one side are stopped by placing a brick on the top of each (see *d*, fig. 69,—this woodcut, it will be observed, does not represent a Silesian kiln, but an English one,

designed by the late Mr. Rogers), those on the opposite side being left open; while on this second side the openings or draught holes are stopped by bricks, *c'* (see fig. 69), the holes on the first side being left open, as at *c*. The kiln is now lighted by means of sticks of easily inflammable wood introduced into all the openings, *c*, on the left. A current of air is established through the transverse channels in the coal, in the direction indicated by the arrows shown in fig. 69. After the lapse of six or eight hours the fire will have reached the opposite ends of these channels, when the chimneys on the left, *d*, and the draught holes on the right, *c'*, must be opened, and the chimneys on the right, *d'*, and the draught holes on the left, *c*, must be closed. This, however, should only be done when the fire has regularly spread through the entire extent of the channels. Special care in this respect at the commencement will prevent further trouble afterwards. According as the weather is stormy or settled, the direction of the currents of air through the kiln may be changed from every two to four hours. Should the coking be found to proceed irregularly, it may be necessary to keep open some of the chimneys on one side longer than others, and, consequently, not to change the direction of all the currents at once. Irregularity in the coking may result either from the quality of the coal or negligence in piling it in the kiln; and in either case the yield will be diminished.

In the management of the process the work of the coke-burner is reduced to keeping open the transverse channels in the coal by raking out any pieces of coal which may fall into them and obstruct the passage of the air, and by preventing their sides from sintering together. For this purpose he uses a slender iron rod, somewhat bent at one end. The re-opening of a channel which has once become stopped is attended with much difficulty, and is generally impracticable; and if several neighbouring channels are closed, the process is thereby much impeded. In windy weather the draught of air through the kiln must be carefully regulated by closing, in a greater or less degree, the chimneys. Any cracks which may occur during the process in the covering on the top of the coal must be well stopped in order to prevent the ascent of currents through them. The proper regulation of the draughts through the kiln has an important influence upon the quality as well as the yield of coke.

In about eight days the process will be completed, as may be known by the escape of white flame from the chimneys and the hardness which is perceived on plunging an iron rod through the cover on the top. All the openings must now be closed, and in the course of two days afterwards the fire will have become gradually extinguished. One of the end walls is now taken down and the coke removed. The coke at the height of the channels will be separated into two distinct layers; that in the upper layer especially is remarkably beautiful (*sic*), dense, hard, and when carefully withdrawn is frequently in pieces 3 feet long and 1 foot in diameter. The yield per 7·768 English cubic feet of coal ranged from 241·25 to 261·87 lbs. avoirdupois. The loss in weight is 20 per cent. of the coal, an amount which, according to the

quality of the coal, is often much reduced. For the measure of coke above mentioned the workmen received (in 1851) just over $1\frac{3}{4}d$. The coke thus produced is stated to have yielded most excellent results in the cupola (i.e. the furnace commonly used for remelting pig-iron), 1.36 English cubic feet being used to melt from 283 to 510 lbs. avoirdupois of pig-iron, according as it is intended to be run into thin vessels (*Potterie*) or heavy castings.

Experiments have been made near Saarbrück with kilns 10 feet high, having in the middle of each side a second row of draught holes; but the result was unfavourable, and the kilns were abandoned.

Several years after the publication of the preceding description,⁷ the same process was patented in England. On the 28th January, 1857, the late Mr. Rogers, of Abercarn, communicated to the Institution of Mechanical Engineers in Birmingham a paper on the manufacture of charcoal and coke, in which he introduced to their notice the process in question.⁸ In that paper the following passage occurs:—“A short time ago a plan was mentioned to the writer as having been used in Westphalia, by which wood was charred in small kilns; as the form of kiln described was quite new to him, it led him to some reflection as to the principles on which it acted, which were found to be so simple and effective that he determined to apply them on a large scale for coking coal. The result has been that in the course of a few months the original idea has been so satisfactorily matured and developed that, instead of coking six tons of coal in an oven costing £80, 150 tons of coal are now being coked at once in a kiln costing less than the former single oven.” The description and drawings of the kiln (see fig. 69) contained in the paper prove, however, that in every essential point it is identical with that which I have just described: Mr. Rogers was therefore under a misapprehension in supposing that coal had not previously been coked in such kilns.

The theory of coking by this method is perfectly intelligible. The coal surrounding the transverse channels is ignited, and, through these, currents of air are established. Heat is thus developed partly by the combustion of the coal in the vicinity of the channels, and partly by that of the volatile products arising from the destructive distillation of the coal. The coking will, therefore, proceed simultaneously upwards and downwards. No currents, as has already been stated, can ascend through the coal above the channels, if the kiln be properly attended to; and, obviously, none can descend from above: consequently, the air which sustains combustion can only enter the kiln through the lateral draught holes. At the conclusion of the process an accumulation of tarry matter always occurs immediately under the coal at the top of the kiln, which would further tend to prevent the descent of air from above as well as the ascent of currents from below; and it is there that the most solid coke is produced.

⁷ It was also published in England in 1855. *Vide* Chemical Technology, Bailière, London, i. 117.

⁸ Proceedings of the Institution of Mechanical Engineers, 1857, p. 31.

In South Wales, and I believe also in other districts, kilns of this kind have been erected of not less than 15 feet in width from wall to wall, measured within. The transverse channels have been made by suitably piling lumps of coal without the use of poles. When the coal is of different sizes, it is advantageous, according to Mr. Rogers, to place the smaller pieces towards the top of the mass. In these larger kilns the mass becomes well ignited in from twenty-four to thirty-six hours. During the process the workman walks on the top of the coal; and from time to time he thrusts through different parts of the surface an iron bar, which is easily pushed down until it reaches the mass of coke. In this way the height to which the coking process has reached is satisfactorily ascertained: if he finds it to have progressed higher at one part than at another, he closes the chimney communicating with that part, and so retards the process there. When the mass has been coked up to the top, which takes place in about seven days, it is quenched with water, and the coke withdrawn in the manner already described.*

"The new kilns," writes Mr. Rogers, "have proved entirely successful; they are already in use at some of the largest ironworks in the kingdom, and are being erected at a number of other works. The great saving in the first cost of oven, economy in working and maintenance, increased yield, and improved quality of coke, will probably soon cause this mode of coking to supersede the others now in use. The kilns are most advantageously made about 14 feet in width, 90 feet in length, and 7 ft. 6 in. in height: this size of kiln contains about 150 tons of coal."

Mr. Rogers asserted that an outlay, in plant, of only 4*l.* was required to produce one ton of coke per day from the Welsh coals, and that the cost of working does not exceed 6*d.* per ton. In some places the coal has been actually tipped into the kiln from the colliery waggons, and the coke waggons were afterwards run into the kiln to be loaded direct from the mass of coke produced, thus reducing the labour to a minimum. The kilns need only be built of rough rubble-work with a plain lining of fire-brick and without any ironwork, so that the expense of repairs amounts only to a small sum. This exactly accords with Brand's experience of the German kilns.

When interrogated at the meeting before which the paper was read as to the yield of coke by this method, Mr. Rogers replied that 18 cwt. per ton of Welsh coal had been obtained, an amount nearly equal to that of the carbon which existed in the original coal. It is hardly necessary to observe that this statement *must* be erroneous. It does not appear that the proportion of water retained by the coke after quenching had been determined; and if this had been done, the result would probably have been widely different. Mr. Riley informs me that he found as much as 22 per cent. of water in coke prepared at the Dowlais Ironworks by the method in question.

* I extract these details from the paper, above referred to, in the Proceedings of the Institution of Mechanical Engineers, 1857, p. 82.

In 1859 I visited several of the large ironworks in South Wales where these kilns had been tried, and I enquired particularly concerning the results. Opinions on this subject were certainly not concordant. At the Dowlais Ironworks they were erected, and after repeated trials abandoned. Mr. Menelaus, the manager of those works, considers them to have been a complete failure; and informs me (June 1873) that, after making allowance for the water in the coke, the yield was "very bad indeed."

The Ebbw Vale Iron Company also made trial of them, and Mr. Adams, the then manager, informed me that they appear to be suitable for one kind of coal, but that for their usual good coal they are wasteful and expensive; much of the large coal which is used to form the transverse channels is burned away, and, as he quaintly observed, "You might hunt badgers through the coke." At the Pontypool Ironworks I inspected one of these kilns from which the coke had been partially drawn, and I remarked that a good deal of the coal in the vicinity of the draught holes appeared to have burned away: some of these kilns were much higher than I had seen elsewhere. Experiments have been made at these works with kilns having double rows of draught holes on each side; but I was informed the result was unsatisfactory.

COKE-OVENS.

In its simplest form a coke-oven is a flat-bottomed chamber, arch-roofed, made of fire-brick or other refractory material, provided with two openings, one in the roof to serve as an outlet for the volatile products of carbonization and as an inlet for introducing the coal, and the other in the circumference or wall to serve as a doorway for withdrawing the coke. Many years ago Parkes described ovens of this kind which were in use at the Duke of Norfolk's colliery near Sheffield.¹ Each oven was a circular brick building, 10 feet in diameter within, having a floor laid with common bricks set edgewise. The wall of the oven, which was 18 inches thick, rose perpendicularly 19 inches above the floor, and was surmounted by a conical roof, of which the apex within was 22 inches above the floor. Good bricks were used, and laid so closely as to prevent the passage of air through the joints. The entire height of the oven from the floor to the top of the arch, outside measure, was 5 feet. The floor was raised 3 feet above the ground, in order that a wheelbarrow or low waggon might be placed under the doorway, and receive the coke as it was raked from the oven. The oven was enclosed up to the top by four vertical walls, 20 inches thick, of rough unhewn stone. The space between these outer walls and the exterior of the circular oven was filled with soil or rubbish, which was well rammed with a view to strengthen the work, and more effectually to exclude the air.

¹ Chemical Catechism, 12th ed. 1826, p. 453.

Parkes has given the following excellent description of the mode of conducting the process, which is generally applicable to coking in ovens as practised at the present time. When once the ovens are heated, the work goes on night and day without interruption. Small refuse coal is thrown in through the hole in the top, sufficient to fill the oven up to the springing of the roof, and then levelled with an iron rake, after which the doorway is built up with loose bricks. The heat which the oven acquired in the preceding operation is always sufficient to ignite the new charge, combustion being sustained by the entrance of atmospheric air through the joints of the loose bricks in the doorway. In two or three hours it is necessary to check the influx of atmospheric air by plastering up the doorway with a mixture of wet soil and sand, except the *top* row of bricks, which is left unplastered all night. Next morning, after the charge has been in the oven 24 hours, that row of bricks is also completely closed; but the chimney is left open until the flame from the hole in the roof disappears, which generally occurs after a further lapse of 12 hours. A few loose stones are now laid on the top of the chimney, and closely covered with a thick bed of sand or earth, so as to cut off communication with the atmosphere. In this state the oven remains for 12 hours more in order to complete the operation. The doorway is then opened, and the coke raked out into wheelbarrows or low waggons, to be carted away. About two tons of coal are put in at each charge. The coke thus produced is stated to have been ponderous, extremely hard, light-grey, bright and metallic in lustre.

In such an oven the coal is subjected to destructive distillation, and the volatile products, as they escape from the surface of the mass, meet with atmospheric air and burn, with the evolution of much heat. Combustion being thus sustained over the top of the coal, the process of coking is gradually propagated downwards to the bottom. As the coal immediately underlying the incandescent stratum is evidently in the same condition as coal undergoing distillation in a close vessel—for air is supposed only to enter the oven *above* the top of the coal—a current of inflammable gas and vapour will continue to ascend until the lowermost stratum of coal is converted into coke. When the process of coking is properly conducted, the carbonization of the coal is effected by the heat resulting from the combustion of the volatile products, and not in a sensible degree from that of the coke formed. So long as these products continue to be evolved, the charge will be secured from contact with atmospheric air, and destruction of coke by combustion thereby prevented. The entrance of air into the oven *below* the surface of the coke would obviously lead to an opposite result.

CHARGING OF THE OVEN.—Charging, as already stated, is conveniently effected through a hole in the roof, to which the coal is conveyed on a railway along the top of a row of ovens.

CLOSING OF THE MOUTH OF THE OVEN.—The mouth of the oven may be stopped either by building it up with bricks, or by a door consisting of a framework of cast-iron, filled in with fire-bricks. This

door may either be hinged, or it may be raised and lowered by means of a chain passing over a pulley above, and having a counterpoise weight at the other end; or a pair of hinged doors may be used.

DRAWING THE COKE.—This process is usually conducted in the following manner in the case of rectangular or nearly rectangular ovens:—On the floor of the oven, at the back, is placed an instrument called a *drag*, which consists of a strong piece of flat iron, having attached to it at right angles a rod of iron sufficiently long to protrude beyond the front of the oven. This drag, which is said to have been invented by the late Mr. John Cox, is placed in the oven before charging, and left there during the process of coking, after the completion of which the whole mass of coke may be drawn out at once by means of a windlass in front, with which the protruding end of the drag is connected by a chain. In some ovens, only the transverse piece of the drag is left in the oven during coking, in which case there is made from front to back, in the middle of the floor of the oven, a gutter, along which an iron rod, bent at one end (as shown in fig. 70) and called the *needle*, is pushed with the bent-up part flat-wise, until this end passes under and behind the drag. By now turning the rod, so as to bring it into the position shown in fig. 70, and pulling it forwards, the coke is drawn out of the oven in one mass. Before charging, the gutter is covered over with little pieces of bar-iron, in order that it may not become obstructed. By this arrangement the destruction of iron which occurs when the entire drag remains in the oven is considerably diminished.

A drag of the latter description is represented in the accompanying woodcuts, figs. 70 and 71. The needle is shown fixed in the centre of



Fig. 70. Drag in vertical section, with needle attached.

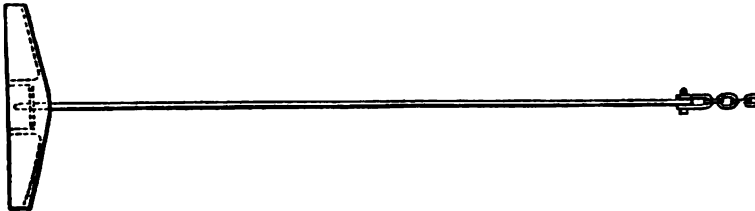


Fig. 71. Drag in plan, with needle attached.

the transverse piece, which is made of cast-iron, ready for drawing the coke; the transverse piece is supported on each side of the centre by a cross-bracket, as indicated by the dotted lines in fig. 71.

A drag of the former description, the whole of which is left in the oven during the process of coking, is represented in the woodcuts, figs. 72 and 73, on p. 434. The transverse piece consists of a short length of an ordinary rail; and in order to prevent the ends from bending, to which they would be liable if the transverse piece were attached to a rod in the centre, a bent rod is employed, which

is attached to the rail near each of its ends, as shown in fig. 73. I

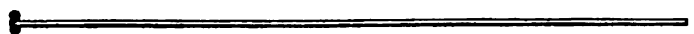


Fig. 72. Fixed drag, with rail in section.

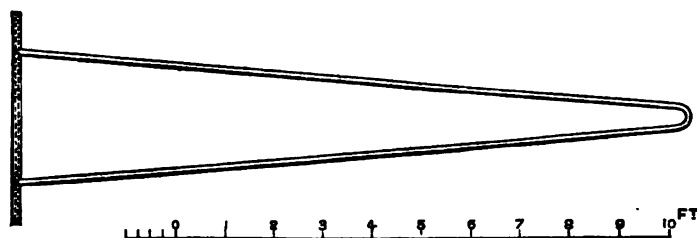


Fig. 73. Fixed drag, with rail in plan.
The scale applies also to figs. 70, 71.

am indebted to Mr. Menelaus for the drawings from which these woodcuts are taken.

Instead of *drawing* out the coke, it may be *pushed* out through the mouth of the oven, by a suitable apparatus, capable of being moved on a railway along the back of a single row of ovens.² This method of drawing has, for many years, been employed at the Cyfarthfa and the Beaufort Ironworks, and is, I am informed by Mr. Menelaus, now (1873) extensively used in Germany.

When the coke is not drawn or pushed out in mass, it must be removed in pieces, which will obviously occasion a greater expenditure of time and labour, and the oven will in consequence lose much heat, especially if water be injected into it to extinguish the coke.

EXTINCTION OF THE COKE.—As soon as the coke is drawn, and sometimes previously, it is extinguished with water, of which, a copious supply should be at hand.

DIVERSITY IN THE CONSTRUCTION OF COKE-OVENS.

The ingenuity of inventors has been much exercised on the subject of coking, and the records of patented inventions abound in descriptions of coke-ovens; but there are only few ovens which present decided and important differences in construction.

Ovens have been made circular, oval, or rectangular, and of very variable dimensions; and contrivances have from time to time been adopted with the following objects:—

I. The prevention, as far as practicable, of the escape of heat from the oven.

II. The introduction of air so as most completely to burn the volatile matters evolved from the coal, without burning the coke produced.

² Engravings of such apparatus are given by Dieudonné in his "Mémoire sur la Fabrication du Coke à Forbach et Hirschbach," Ann. des Mines, a 5, 1859, xv. 489.

III. The utilization of the waste-heat in such a manner as to cause the process of coking to proceed simultaneously from below upwards, and from the sides inwards, as well as from above downwards.

IV. Facilitating the removal or *drawing* of the coke from the oven, with the view, not merely of diminishing labour, but also of reducing as much as possible the amount of heat, which, in a greater or less degree, must necessarily be lost during this part of the operation.

The first object has been accomplished by making the walls thick, and covering the roof with sand, or some other bad conductor of heat; by building a second arch at some distance over that which forms the roof of the oven proper, and causing the products of combustion to pass between the two arches on their way to the chimney; and by building two rows of ovens back to back, or a number of ovens radially round a central chimney.

The second object has been effected by allowing air only to enter the oven above the top of the coal in several places, through channels in the brickwork; or by burning the volatile products of carbonization outside the oven, and so heating it like a retort.

The third object has been effected by causing the volatile products of combustion to circulate through flues under the bottom, and in the walls forming the sides of the oven.

The fourth object has been attained by building the oven not quite rectangular in plan, but with the walls slightly diverging, and the bottom slightly sloping downwards, towards the front, in order to facilitate the use of the drag.

DESCRIPTIONS OF PARTICULAR COKE-OVENS.

The following typical series of coke-ovens has been selected for description with the view of presenting the most important principles of construction, and some of the modifications in detail, which seem to be of most practical importance to the metallurgist. It should, however, be stated, with regard to the coke-ovens which have been invented, that their name is legion, and that a description of them all would fill a large volume.

Cox's COKE-OVEN.

This oven was invented by Mr. John Cox.³ I am indebted to the Ebbw Vale Iron Company for the drawings from which the annexed woodcuts, figs. 74, 75, and 76, were made. The oven consists of a nearly rectangular chamber of fire-brick, arched over from side to side, and open in front. The bottom is flat, and inclines slightly downwards and forwards (see fig. 75, *c*). The width between the side walls increases gradually, but only in a small degree from back to front, as shown by the dotted lines, fig. 76. At a distance above the arch forming the roof is a second arch, fig. 74, *β*, and fig. 75, *c*.

³ The principle of the oven described differs from the claim made in the specification of a patent (No. 8709, A.D. 1840) granted to Cox, and entitled "Ovens for making Coke and other purposes."

The side walls and the front wall above the arched mouth are carried up to a considerable height, and the space enclosed by these walls

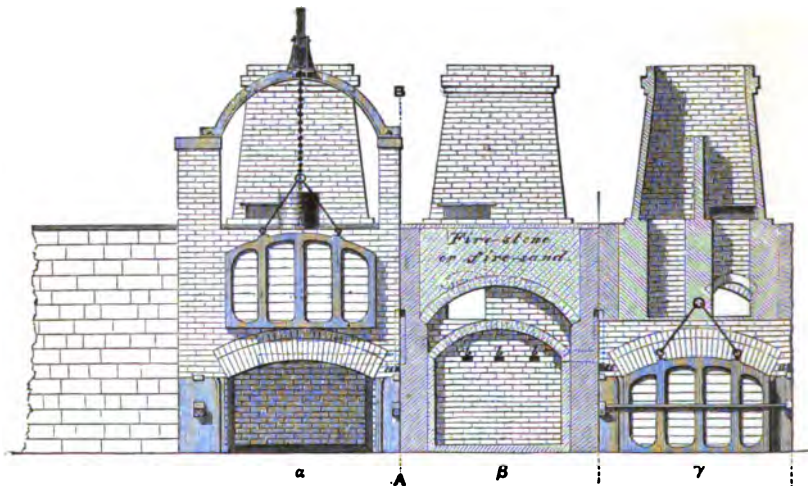


Fig. 74. Cox's coke-oven.

a Front elevation.

b Vertical section on the line
c d, fig. 76.

c Vertical section of the chimney, on the line
e f, fig. 76, above the top of the lower
arch, which is shown in front elevation,
with the door fixed in its place.

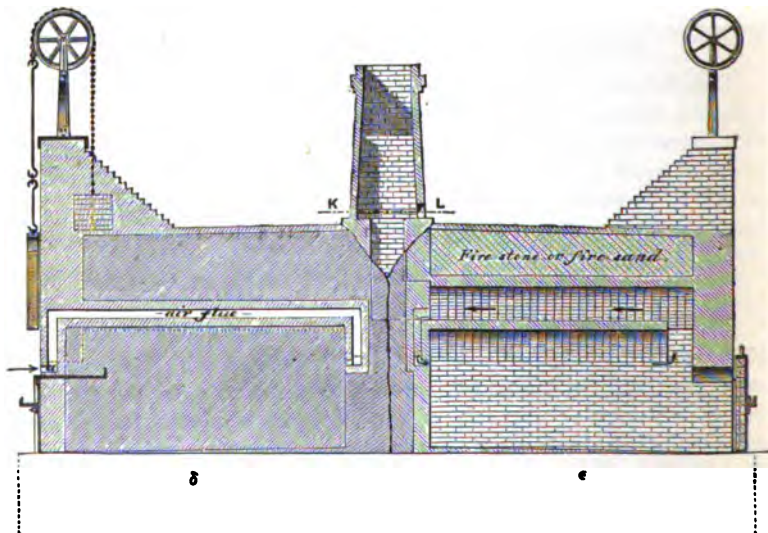


Fig. 75. Cox's coke-oven.

d Vertical section on the line a b, fig. 76.

e Vertical section on the lines c d and e f, fig. 76.

and the chimney at the back is filled with sand, so that a considerable amount of matter is thus accumulated, which has the effect of retaining much of the heat generated during the process of coking. In the

front and on the right of each oven is an air-flue, *a*, fig. 75, δ , and fig. 76, which passes upwards, backwards, and downwards in suc-

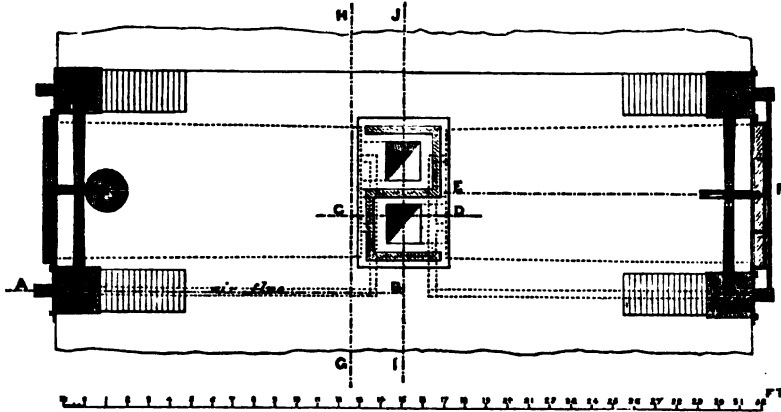


Fig. 76. Cox's coke-oven. Plan of the oven, showing a horizontal section of the chimney on the line *K L*, fig. 75.

cession, and then nearly across the upper part of the back of the oven (see the dotted lines in fig. 76), with the interior of which it communicates by three openings, *b b b*, fig. 74, β .

Between the front wall of the oven and the lower arch a space is left, as shown by the arrow in this part, fig. 75, ϵ . The space between the two arches communicates at the back with the chimney. From the engravings it will be observed that the ovens are built back to back in double rows. There is but one chimney to every two ovens, which up to a certain distance from the top is divided by a partition wall (see fig. 74, γ), two flues being thus formed, one for each oven. Each of these flues is provided with an opening at *L*, fig. 75, to receive a flat brick to be used as a damper for regulating the draught. The mouth of the oven is closed by a door, consisting of a frame of cast-iron filled with fire-bricks. The door is conveniently raised or lowered by means of a chain passing over a pulley, and having a counterpoise weight attached to it, as shown in fig. 75, δ . When lowered, it is securely fixed against the mouth by an iron bar placed transversely, as shown in fig. 74, γ .

The charge is introduced through the mouth, and piled to the uniform height throughout of 3 ft. 6 in. The mouth is then closed by letting down the door, and luting it round the edges with clay or common mortar. The air which supplies combustion enters by the flue, *a*, and passes into the oven at the back, through the three openings, *b b b*. The products of combustion rise through the space in front of the lower arch, and then pass backwards into the chimney through the space between the two arches, as shown by the direction of the arrows in fig. 75, ϵ . These ovens are expensive in construction; but I am informed on good authority that they have been found in practice to be sufficiently advantageous to justify

the outlay. The admission of air can be surely regulated, and the amount of waste-heat retained by means of the arrangement of the two arches with the superincumbent mass of matter effectually contributes to the coking of the next charge of coal. The coke is quenched with water before drawing, under the impression that more sulphur is thereby removed, but the effect of this practice is to injure the bottom and increase the expense of repairs.

The late Mr. Parry, of the Ebbw Vale Ironworks, informed me, in 1861, that he had then recently effected the following improvement in these ovens, which is especially adapted for coking small coal. In the wall at the back are four vertical flues, in connection with four flues immediately under the bottom, in the direction of its length. The air which sustains combustion is admitted only at the front into the space between the two arches (fig. 75, *e*), and not below the lower arch into the chamber containing the coal. The gases evolved are thus burned on the *outside* of this chamber, and the gaseous products of combustion pass backwards and then downwards through two of the flues at the back, and thence forwards through two of the flues under the bottom, returning by the other two flues under the bottom, and ascending through the other two flues at the back into the chimney. No flame appears at the top of the chimney, which is the case in the old ovens; so that all the heat developed by the combustion of the gaseous products is applied advantageously in the coking process. By this arrangement 50 per cent. more small coal can be coked at a time and with much greater economy than in the old ovens, as less coal is burned to waste than in those ovens. A stratum of small coal 4 feet thick may be uniformly coked to the bottom in the new ovens, whereas in the old ovens, in a stratum 3 feet thick, there was always a layer at the bottom, not less than 6 inches thick, of soft coke due to imperfect carbonization.

JONES'S COKE-OVEN.

This oven was patented ⁴ by the late Mr. Edward Jones, manager of the Russell's Hall Furnaces, near Dudley, belonging to the late Mr. S. H. Blackwell. The annexed woodcuts, figs. 77-83, were made from drawings prepared under the direction of my friend Mr. George Shaw, of Birmingham. The oven is built wholly of brick. The bottom is rectangular and flat, and inclines forwards and downwards from *a* to *b*, fig. 78. The sides and back are vertical; and above is an arch enclosing the top; at the front, *b*, is an arched opening, or mouth, which may be closed by movable brickwork. In the centre of the arch forming the top of the oven is a circular opening, *s*; and at the back, *r*, is a narrow opening extending across: both these openings are closed with movable covers, around the edges of which sand is piled to render them air-tight. In the back wall ⁵

⁴ Specification No. 2738, A.D. 1858.

⁵ The reader should be careful to distinguish between the back wall of the oven itself, and the wall which forms the back of the whole structure.

there are two arched openings, *c, d*, fig. 80, from which flues pass downwards and forwards under the bottom, as shown by the arrows in fig. 81; and then, as shown by the arrows at *e, f*, in the same figure, return to the back, where they communicate with the flues, *g, h*, which ascend into the chimney, *i*. The height of the chimney above the oven is 8 feet; and the opening at the top is 14 inches square,

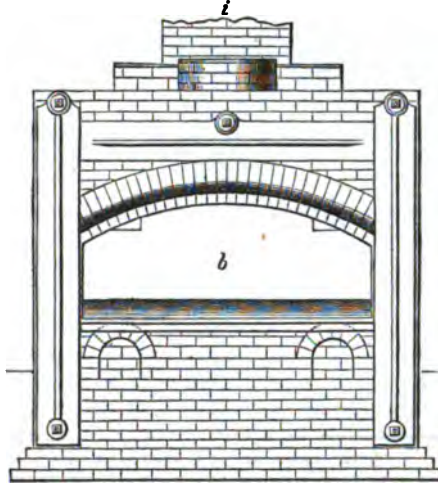


Fig. 77. Jones's coke-oven. Front elevation.

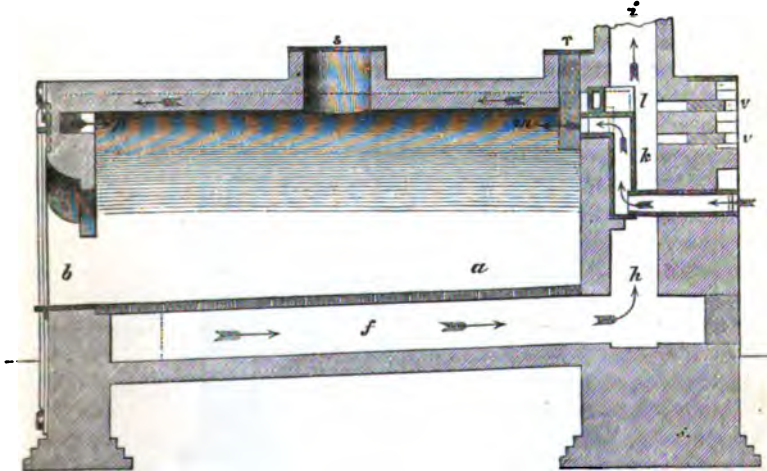


Fig. 78. Jones's coke-oven. Longitudinal vertical section.

and is provided with a damper. In figs. 77 and 79 are shown arched openings, the two shown in fig. 77 being in the front, and the other two in the back of the oven, by means of which the flues under the bottom of the oven may be cleaned out from time to time: they are closed with brickwork when the oven is in use. At the back are two cast-iron pipes, *k, l*, which communicate with the external

air, and pass through the lower part of the chimney, *i* (see fig. 78), but without communicating with it; the opening of each pipe is provided with a sliding iron damper (see fig. 79). The pipe, *k*, passes from the chimney into the oven at *m*, fig. 78; and the pipe, *l*, after rising to a level with the top of the oven, opens into two flues, *n*, *o*, fig. 80, which

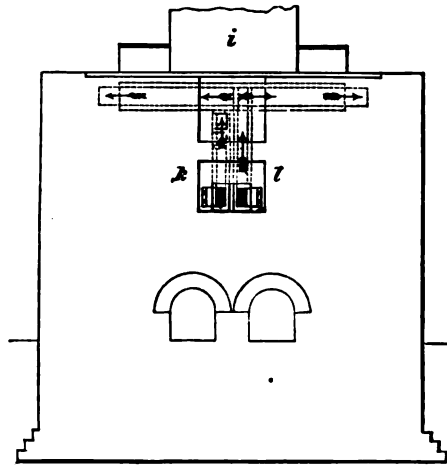


Fig. 79. Jones's coke-oven. End elevation.

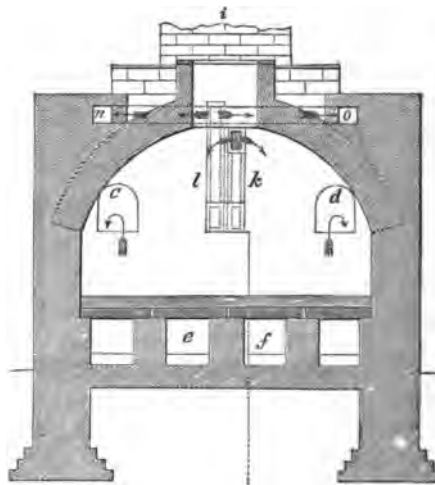


Fig. 80. Jones's coke-oven. Transverse vertical section.

pass round to the front of the oven, and, reuniting, enter it through the opening at *p*, figs. 78 and 82. These flues should lie immediately upon the arch, and not at a distance from it, as shown in the woodcuts. At the back are openings, *v v*, fig. 78, through which the inside of the oven and the pipes may be inspected: they are closed by movable bricks. It will be observed that the bottom of

the oven is at a considerable height above the foundation: this was rendered necessary by the badness of the ground on which the ovens were erected. The brickwork is suitably braced by cast-iron plates and wrought-iron tie-rods, as represented in fig. 77.

About $4\frac{1}{2}$ tons (1 ton = 20 cwt. of 112 lbs.) of the slack of the Ten-yard or Thick-coal are mixed with 1 ton of coal-tar pitch, previously

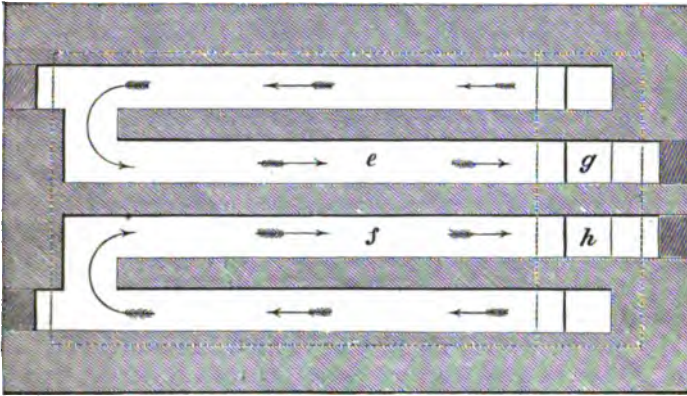


Fig. 81. Jones's coke-oven. Horizontal section beneath the floor of the oven.

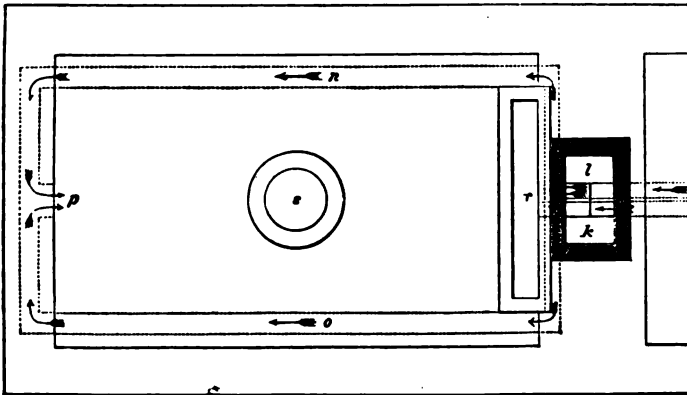


Fig. 82. Jones's coke-oven. Plan.

crushed between rolls, of which the upper one is fluted. This mixture is dropped into the oven through the opening, *s*, in the top, and spread evenly over the bottom.* The mouth of the oven is then stopped by

* Although this oven was used when I saw it in operation for coking a mixture of coal and pitch, ye* it might equally be applied to the coking of unmixed coal. I have introduced a description of it in this place, because it well represents a

particular construction of oven, in which the hot waste-gases are made to pass under the floor, and so cause coking to proceed simultaneously from below upwards, and from above downwards.

building up a wall of loose bricks. At some distance in front of this wall is placed a door of sheet-iron, which is kept vertical by a transverse bar of iron suitably fastened at each end. Between the outside of the wall of bricks closing the mouth, and the inside of the sheet-iron door, a space is thus left, which should be well filled with coke-dust, *so that no air may enter the mouth of the oven.* When the oven is in use, it retains sufficient heat after one charge is drawn to ignite the next. The air to sustain combustion enters at the back through the cast-iron pipes, *k, l*, which are red-hot, so that it becomes much heated in its passage. One portion of the air enters at *m*, fig. 78, through the pipe, *k*, while the other portion traverses the pipe, *l*, passes round to the front, and enters the oven at *p*. Heated air is thus supplied to effect combustion, and the amount can be exactly regulated by the sliding dampers at the ends of the pipes, *k, l*, fig. 79. The volatile products of combustion escape through the openings, *c, d*, fig. 80, at the back, and thence downwards, forwards, and backwards in succession, as shown by the arrows, fig. 81; from *e, f*, they pass into the chimney through the ascending flues, *g, h*. By this arrangement the waste-heat is applied to the heating of the bottom of the oven, so that the coal on the bottom may be subjected to distillation as in a retort. When in good working order, the interior of the oven will be observed, through the openings at the back, to be uniformly heated throughout to bright redness.

The charge is coked in 36 hours, when it might be drawn; but for the sake of convenience in arranging the division of labour, this is not done until after the lapse of 48 hours. After the completion of the process, the coked mass will be found to have receded more or less from the sides and back of the oven. Before drawing, the temperature of the oven is allowed to decrease considerably. The coke is drawn by means of drags, which are represented in fig. 83. The drags are used in pairs; each drag being formed of an iron-casting, and a handle or staff of good hammered iron, *b*, about 13 feet long. The casting is in one piece, and consists of a horizontal plate, *a*, from the broad end of which descends at right angles another plate, *d*, which represents the end elevation. A side elevation of this casting is shown at *e*. At the free end of the staff, *b*, is a hole to receive a hook attached to a chain. There is also another hole into which is inserted the transverse bar, *c*, which is provided with a collar near each end, and connects the two drags together, keeping them parallel while they are being drawn from the oven. Preparatory to drawing, two flat iron rods ($1\frac{1}{2}$ in. broad and $\frac{3}{4}$ in. thick) are pushed along the top of the coke on one side to the back of the oven; and on these, which act the part of rails, one drag is made to slide until the depending part, *d*, drops into the fissure produced by the recession of the coked mass from the back of the oven. The flat bars are then removed to the other side of the oven, and the second drag is introduced in the same manner. By means of a crowbar passed through the longitudinal opening, *r*, figs. 78 and 82, in the top of the oven at the back, the fissure may when necessary be enlarged, and the adjust-

ment of the drags thereby facilitated. After the transverse bar has been fixed in its place, as shown in fig. 83, the drags are pulled out

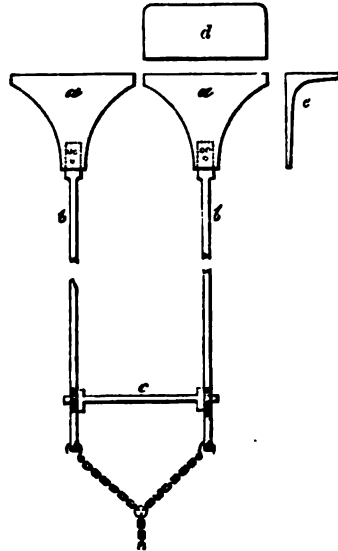


Fig. 83. Drag used in Jones's coke-oven.

by means of a windlass, to which the chain shown in the figure is attached. The whole mass of coke is thus drawn at once, and immediately afterwards extinguished with water. By this arrangement there is no destruction of iron such as speedily occurs when the drag is left in the oven during the process of coking. There were two rows of these ovens, each containing ten; and on the top of each row, which is made level, there is a railway by which the coal may be conveniently carried to the charging holes.

The yield of coke was stated to be about 65 per cent. of the weight of the charge. The coke is firm and brilliant, and well adapted to iron-smelting. The actual cost of coking, exclusive of the cost of pitch, is estimated at $3\frac{1}{2}d.$ per barrow, or from $1s. 9d.$ to $2s.$ per ton of coke, short weight (1 ton = 20 cwt. of 112 lbs.). The price of pitch, when I inspected these ovens in 1859, was $15s.$ per ton: it had risen just previously. It was calculated that the slack virtually cost nothing, as it was paid for by the profit on the *lump-coal* raised along with it.

The advantages of this process of coking are stated to be as follow:—1. The introduction of air heated by the waste-heat of the oven. 2. The air enters immediately under the arch, and as far as possible from the surface of the coal, whereby the volatile products evolved from the coal are effectually burned, and the loss occasioned by the combustion of the coke formed is reduced to the

minimum. 3. The method of drawing, whereby the destruction of the iron in the drags is completely avoided.

Mr. Jones informed me that he had tried various experiments upon coking in this oven non-caking coal-slack *per se* under a layer of lime, of blast-furnace slag, etc., but without success. I witnessed an experiment of this kind with a covering of a mixture of coke-dust and the siliceous sifted residue of the Leighton-Buzzard iron ore (which consists chiefly of hydrated sesquioxide of iron mixed with sand); and Mr. Jones was of opinion that the result was the most successful he had up to that time obtained. A statement of the object in view in making these experiments will be found on p. 309.

When the bottom of a coke-oven is heated by flues underneath, as in the case of this oven, the mass of coke is always divided horizontally into two distinct strata, and the line of separation between them is stated to be that of *least* heat.

THE APPOLT COKE-OVEN.

The following description, illustrated by the accompanying woodcuts, figs. 84—88, is to a great extent a literal translation of that published by the inventors, the brothers Appolt.⁷

With the addition of certain modifications which experience has shown to be useful, this description applies to an oven at the works of Messrs. Pinart Brothers, at Marquise, in the Department of Pas-de-Calais, in France, which was first lighted on the 1st September, 1857.

It consists essentially of a large rectangular brick chamber—5·23 metres (about 17 ft.) long, 3·49 metres (about 11 ft. 6 in.) wide, and 4 metres (about 13 ft.) high—divided by partition walls, 0·12 metre (about 4½ in.) thick, into a series of twelve compartments, each of which may be regarded as a kind of retort, 1·24 metre (about 4 ft.) long, and 0·45 metre (about 1 ft. 6 in.) wide at the base, and 1·12 metre (about 3 ft. 8 in.) long and 0·33 metre (about 13 in.) wide at the upper part. Each compartment, *k*, fig. 84, has its own walls, and is surrounded by a free space, *i*, from top to bottom; and all the similar spaces thus existing round the twelve compartments are in free communication, forming in reality one continuous space. The distance between the corresponding walls of neighbouring compartments varies from 0·2 metre (rather more than 7½ in.) to 0·25 metre (rather more than 9½ in.). The series of compartments is contained within four vertical walls of fire-brick, between which and the mass of brickwork on the outside is a space, *e*, filled loosely with some substance in powder, which is a bad conductor of heat, and which will in a certain degree permit the dilatation of the brickwork within. All the compartments are connected solidly together by strong fire-bricks,

⁷ Annales des Mines, s. 5, 1858, xiii. 417.

b, fig. 84, extending across the spaces, i, and placed quincuncially in the partition walls and the surrounding vertical walls as shown in the accompanying diagram: there are 60 of these bricks in each compartment. At the top of each compartment is an opening, o, fig. 84, formed by the walls on the narrow sides rising vertically, and the walls on the wide sides approximating upwards in a series of steps; and at the bottom is an opening, p, provided with a cast-iron door. The partition walls of the

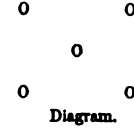


Diagram.

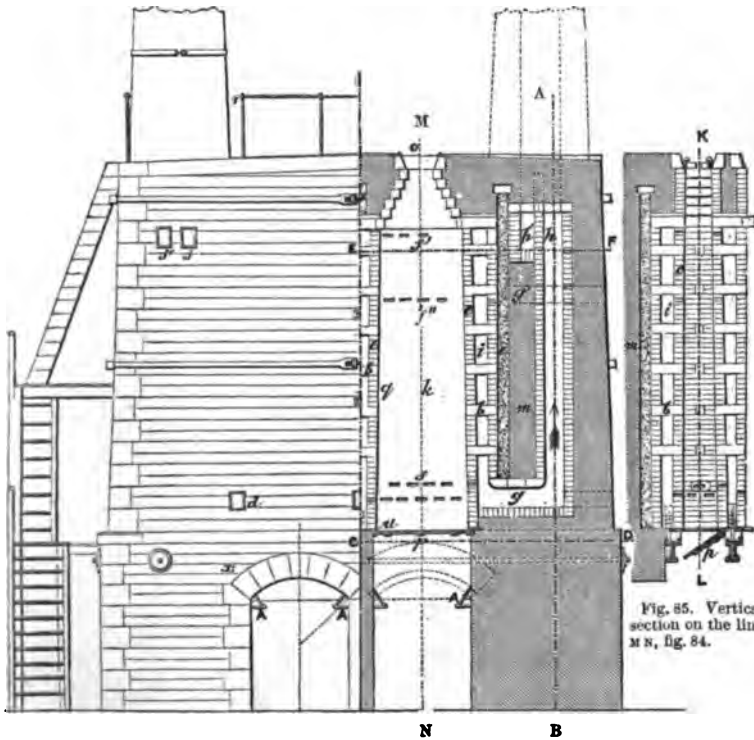


Fig. 85. Vertical section on the line M N, fig. 84.

Fig. 84. Appolt coke-oven. Front elevation. | Vertical section on the line M N, fig. 85.

compartments rest upon frames of cast-iron, u, fig. 84, 0.03 metre (about an inch) in thickness, which are supported in the direction of their length by brick arches 0.24 metre (about 9½ in.) thick. These arches are so arranged that an open space is left under each compartment. Instead of arches, cast-iron bearers may be employed. The bottom of the free spaces is covered with fire-brick to the height of 0.27 metre (about 10½ in.) above the framework of cast-iron. Under the compartments and in the direction of their short axes, two parallel arched passages, see fig. 87, extend through the building. The outer walls of the oven are vertical up to the frame-

work of cast-iron, from which they incline inwards to the top. The cast-iron doors which close the compartments at the bottom are 0.02 metre (about $\frac{3}{4}$ in.) thick. Each door is strengthened by three transverse bars of wrought-iron, by means of which it is firmly fixed to an iron rod supported at each end by a staple let into the under side of the cast-iron frame, a hinge being thus formed. The end of the suspending rod which is directed towards the wide side of the oven is prolonged, and the projecting part is squared so that it may be turned by a key like that of a piano. In the centre and passing through the middle transverse bar of the door is a pivot, and on this turns a flat bar, of which the ends may slide into grooves in pieces projecting from the

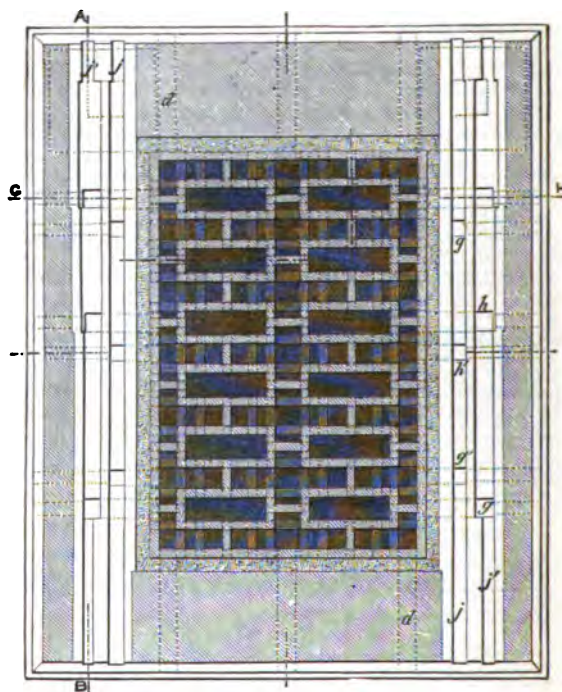


Fig. 86. Appolt coke-oven. Horizontal section on the line $x\ x$, figs. 84, 87.

under and short sides of the cast-iron frame: the door may thus be securely fastened. It may be shut by a key, which passes through an iron pipe built in the brickwork and firmly fastened to the iron frame, in order that it may not turn round with the key.

In a space included between the vertical heights of 0.42 metre (about 16 in.) and 0.57 metre (2 ft.) from the bottom, the partition walls of each chamber are traversed by two rows of small horizontal openings, f , fig. 84, 0.14 metre ($5\frac{1}{2}$ in.) long and 0.02 metre (about $\frac{3}{4}$ in.) high: there are nine such openings on each wide side and three on each narrow side. At the upper part there are three similar openings, f' , on each wide side only. Through these openings the

volatile products evolved during the coking of the coal pass into the surrounding open spaces, in which they are burned by atmospheric air admitted through holes in the wide sides of the oven. It is asserted that the heat thus developed more than suffices to coke the whole of the coal from which these volatile products have been derived.

Experience has proved the utility of the small openings, f , at the upper part, or somewhat lower as at f' ; for in operating upon certain caking coals, if the whole of the tar evolved is obliged to traverse the lower part of the cake of coke, too much carbon may be deposited,

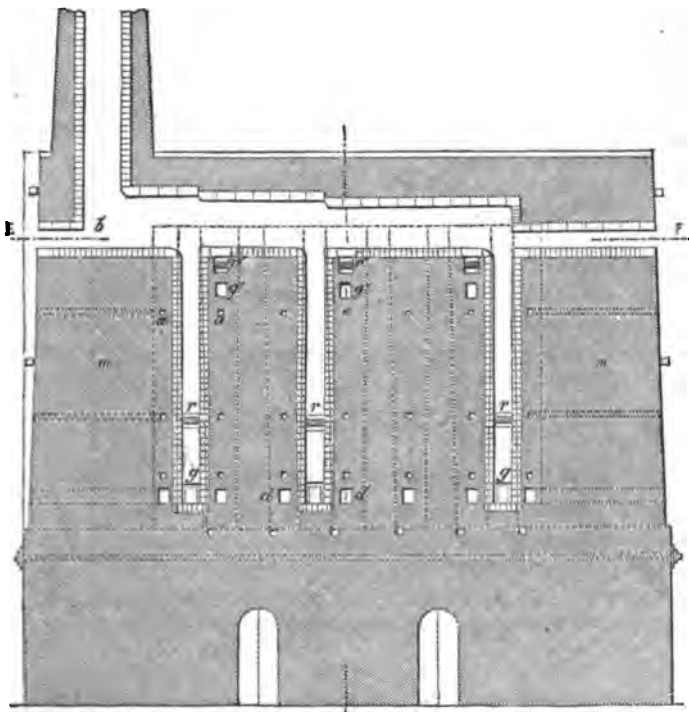


Fig. 87. Appolt coke-oven. Longitudinal vertical section on the line A a, figs. 84, 86.

and the descent of the coke be thereby obstructed. The height of all the small openings, f, f' , is purposely restricted to 0.02 metre (about $\frac{3}{4}$ in.) in order that the fine coal may only produce a small talus; and in the event of their becoming choked with little masses of coke, the latter may be withdrawn of themselves in following the general mass of coke as it shrinks. In the wide side walls of the oven are the flues, g, g' , which receive the products of combustion from the spaces surrounding the chambers and convey them to the chimneys. There are twelve vertical flues in all—three below and three above in each of these walls. Those below are square in section, 0.25 metre (about $9\frac{3}{4}$ in.) on the side; at first they pass

horizontally to the middle of the outer brickwork, then ascend vertically, and open into a horizontal flue, *h*. Those above are 0·20 metre (about 7 $\frac{1}{4}$ in.) long by 0·17 metre (about 6 $\frac{1}{2}$ in.) broad; they also pass horizontally into the outer mass of brickwork, ascend vertically, and open into a second horizontal flue, *h'*, parallel to the first. All these vertical flues have dampers of fire-brick at the top, so that the draught may be regulated at will. The four horizontal flues, of

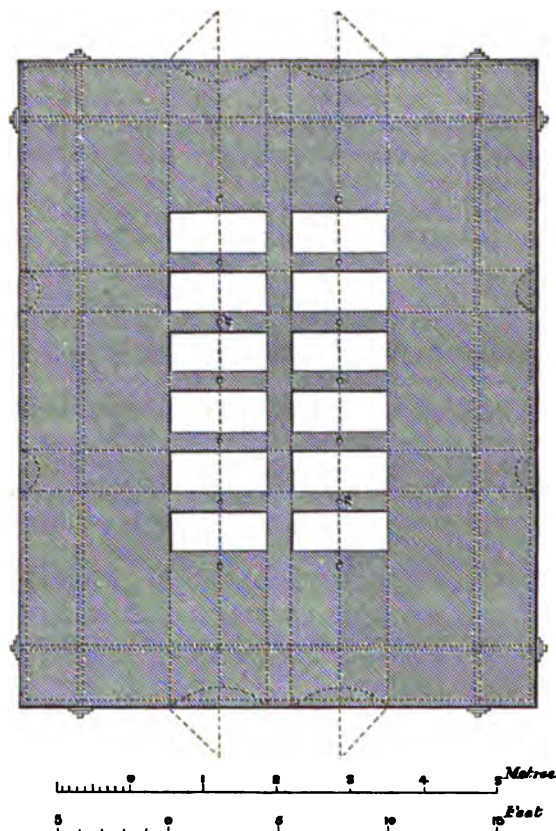


Fig. 88. Appolt coke-oven. Horizontal section on the line c d, fig. 84.

which there are two on each side, *h*, *h'*, have all the same height of from 0·54 metre (about 1 ft. 9 in.) to 0·67 metre (about 2 ft. 2 in.). Into the two outer flues—of which the width is from 0·25 metre (about 9 $\frac{1}{4}$ in.) to 0·29 metre (about 11 $\frac{1}{2}$ in.)—open the six vertical flues from below; and into the two inner flues—of which the width is 0·17 metre (about 6 $\frac{1}{2}$ in.)—open the six flues leading from the upper part of the compartments. The two horizontal flues on each side are separated by a wall of the width of a single brick, and open into a chimney of which the internal sectional area is a square, 0·48 metre (about 1 ft. 7 in.) on the side, and the height above the top of the

oven 5 metres (about 16 ft. 6 in.). There are two chimneys, one on each side; their position is shown in fig. 84. The lower part of the chimneys within, to the height of 1 metre (about 39 in.), is divided by a wall of single brick into two parts, corresponding to the horizontal flues which open into them. At *j, j'*, fig. 84, are openings with iron frames, by means of which the horizontal flues may be cleaned out. It is hardly necessary to remark that every part of the oven exposed to great heat should be made of fire-brick.

The free spaces surrounding the compartments are closed at the top with two courses of fire-brick, upon which is ordinary brickwork of sufficient thickness to prevent the loss of too much heat. A few hollows may be left in the brickwork to allow for the effect of expansion by heat, as shown at *s*, fig. 84. The platform on the top of the oven slightly inclines from the central line towards each of the two long sides, as shown in fig. 84, and is covered with cast-iron plates. The bottom of the free spaces may be cleaned out from the outside of the oven through openings, *d*, fig. 84. There are small openings, *a a*, fig. 87, provided with sliding dampers through the brickwork, which answer the double purpose of supplying air to effect combustion, and of enabling an inspection to be made of the interior of the oven. There are also other small openings, *n*, fig. 88, for the admission of air, through the arches upon which the long sides of the compartments are built. The brickwork is held firmly together by suitable iron tie-rods, as shown in fig. 84.

The oven is charged at the top, and the coke is withdrawn at the bottom and removed in iron waggons. In order to prevent the coke from falling with too much force into the waggon, inclined and projecting plates of cast-iron are fixed in the walls underneath each compartment, as shown at *A*, fig. 84. The mass of coke lodges on these plates, from which it may be detached in pieces and carried away.

MODE OF CONDUCTING THE PROCESS.—The oven is supposed to be new and ready for lighting. At the bottom of each compartment a temporary grate of iron bars is adjusted; and the sides, to the height of 0·3 metre (about 1 foot) above the grate, are lined with fire-bricks placed slanting, in order to prevent the adhesion of the clinker produced in heating the furnace in the first instance to the walls of the compartment: a moderate fire is made, and kept up by throwing in coal at the top, which is allowed to remain open until the walls of the compartments have become red-hot. When this occurs, it is generally kept closed; so that the flame from the temporary grate is compelled to escape through the small openings leading into the surrounding free spaces, and all the interior of the oven is thereby heated. By only partially opening the dampers of the air-flues, a portion of the products of combustion will escape through the outer walls of the oven, and promote their desiccation. After eight or ten days' firing, gradually increased, the oven will be found to have attained the temperature of from 1200° to 1400° C., which is necessary for the commencement of the charging. In order always to ensure an equable degree of heat through the oven, and to simplify the management of the latter by the

dampers and air-flues, it is expedient to charge the two series of compartments alternately. The temporary grate and brick-lining at the bottom are removed from the compartment which it is proposed to charge. The door is closed and securely fixed in the manner previously described, and then covered with a layer of coke-dust about 0·3 metre (about 1 foot) thick: this is done to protect the door from heat, to close effectually the bottom of the compartment, and to prevent loss of heat. The charge of coal is now introduced, and a cover placed over the top luted with coke-dust or clay.

The gases, which are immediately evolved when the coal comes in contact with the red-hot sides of the compartment, pass into the surrounding free spaces, where they are burnt, and so sustain the heat of the oven. An hour afterwards a second compartment is charged in like manner, and so in succession until all have been charged. As the amount of gas produced increases during the day with the number of charges, it is necessary to open the dampers, and all that is required to be done during the night is gradually to shut them again in proportion as the evolution of gas decreases. Carbonization being completed at the end of twenty-four hours, on the following day the coke is drawn from the first compartment at the same time as the charging took place on the previous day. Immediately afterwards the compartment is charged again.

The process is thus continued without interruption, the coke being drawn from each compartment twenty-four hours after it has received its charge of coal. No inconvenience arises from the use of washed coal which still retains moisture. By suitably decreasing the admission of air and the exit of gases from the oven, the charging may be omitted on particular days; and yet the heat will continue sufficiently high to enable the charging to be effected on the following day.

PRINCIPLES ON WHICH THE OVEN IS CONSTRUCTED.—During the process of coking each compartment is in reality a closed vessel, with the exception of the apertures through which the volatile products escape into the surrounding space; and in so far it resembles a gas-retort. No air from without can reach the interior of a compartment, even though cracks may be produced in its walls. In this respect it differs essentially from ordinary coke-ovens, into which air is allowed to enter above the coal undergoing carbonization. If from neglect of the workmen or other circumstances too much air passes into these ovens, a considerable amount of coke may be needlessly consumed; whereas in the Appolt oven this evil cannot occur. By the subdivision of the oven into a series of compartments, each of which is surrounded by burning gas, a very great extent of heating surface is obtained, which in the oven described is nearly 190 square metres for a charge of 17,000 kilogrammes of coal—a surface said to be two or three times greater in proportion than that of the most improved kinds of other ovens. As the coal is divided into masses of but little width, it can be readily penetrated by heat, and, therefore, subjected to *rapid* carbonization. The combustion of the gases in these ovens is stated to be more perfect and active than in ordinary ovens, because air enters through

numerous openings in the outer walls of the oven, and the mixture of air and gases freely circulates through a large extent of space. This result is further promoted by the exit of the jets of gas through numerous small openings, and, in consequence, its more rapid and complete admixture with air. The partial exit of the gases from the lower part of each compartment obviously tends to produce an equable diffusion of temperature through every part of the oven. The changes of temperature which occur in other ovens, from the charging of the coal to the drawing of the coke, are avoided; for, as the charging of the compartments takes place at successive intervals in a well-arranged order, the heat of the oven is maintained at nearly the same degree during the whole course of the operation. The heating surface of this oven, compared with its external surface of brickwork, is greater than in other ovens, and, consequently, much less heat is lost by cooling from without. The vertical position of the compartments is said to be important, as presenting the following advantages:—it is possible *only by this means* (?) to secure the advantageous relation between the heating and cooling surfaces, so that a large quantity of coal may be coked in a proportionately limited space: in respect of its relative power of production it occupies much less space than other ovens: as there is no arch exposed to the action of heat, the oven is more solid, and the coke in dropping down exerts no injurious amount of wear on the sides: as the charging and drawing may be very quickly effected, the walls of the compartments are less liable to be cooled during these operations: the pressure of the column of coal produces a coke of much greater density than that obtained in other ovens.

EXPERIMENTS ON THE FORMATION OF COKE IN THE APPOLT OVEN.—

With a view to ascertain how the process of coking proceeds in the Appolt oven, the following experiments have been made by Vériot and Till-Appolt, and recorded in their paper on the carbonization of non-caking coals (*houilles maigres*).⁸ Four hours after a compartment had been charged, the cast-iron door was opened, when the coal which was in the centre fell out in the same state in which it had been put in, and was even cold. The large quantity of heat which had traversed the walls of the compartment had been expended in forming a lining of coke about 10 centimetres thick adherent to the walls. The internal surfaces of this lining were smooth, shining, and parallel to those of the compartment. The action of the heat had been stopped at the surface separating the coke already formed from the unchanged coal. Two and six hours after charging similar results were observed; but although the thickness of the lining of coke varied with the greater or less duration of the heat, yet it was not directly proportionate to the time of heating, but was relatively less the greater its duration; the reason alleged for this is that the layers of coke formed, being feebly conductive of heat, offered continually increasing resistance to the rapid penetration of the heat. Thus, the last or innermost layers of coke are slowly formed; and there results a cavity parallel to the larger faces of the compartment

⁸ Bulletin de la Société de l'Industrie minérale, 1868-1869, xiv. 751 et seq.

in the middle of the block of coke. The central cavity indicates the movement of the particles of coal towards the layer of coke last formed. The knowledge of the foregoing facts concerning the mode of formation of the coke in the Appolt oven is stated to be of practical importance, in order to determine the precise dimensions of the compartments required for the complete coking in a little less than twenty-four hours of coals varying in degree of caking quality, and to ascertain the most suitable preliminary treatment of each kind of coal or mixture of coals with a view to facilitate its conversion into coke. Experiments in crucibles afford indications as to caking quality, swelling or contraction of the coal during carbonization, etc., which may be trusted to guide practice on the large scale.

INFLUENCE OF WATER ON COKING IN THE APPOLT OVEN.⁹—When moistened coal is coked in the Appolt oven, as in the case of coal which has been washed in order to free it more or less from earthy matter, the water thus retained, provided it be not excessive in quantity, is generally neither injurious to the process of coking nor to the quality of the coke. Water in the coal to the amount of 4 or 5 per cent. causes, it is said, more active combustion of the gases in the spaces surrounding the compartments. Certain coals, however, particularly the semi-caking rich in oxygen (*demi maigres par excès d'oxygène*), do not cake so well and yield less coherent coke when they are put into the oven in a fine state of division, moistened with at most 5 per cent. of water; but coals rich in carbon do not usually present this inconvenience, and as some of them increase in volume by carbonization, it is necessary to counteract that evil, in order that the block of coke may leave the compartment without applying force, which might possibly injure its walls. The remedy is to add as much water to the charge of coal in powder as will considerably increase its bulk,¹ for which purpose the addition of 6 or 8 per cent. of its weight of water will be sufficient. Coal in fine powder thus treated will rather contract than swell during carbonization, and, when carbonized in the Appolt oven, will yield dense coke, though in an ordinary oven the coke from it would be porous and light. The chief reason for such difference in the character of the coke is, it is alleged, the relatively greater height of the charge and the higher temperature in the Appolt oven. It is, however, added that there is not great difference in density, in relation to apparent volume, between pieces from the bottom and top of a block of coke in the Appolt oven, though the former are a little denser than the latter. In a pretty large number of cases, it has been found that the same kind of coal yields denser coke by carbonization in the Appolt oven than in other ovens.

ACTUAL RESULTS OBTAINED IN COKING BY THIS METHOD.—At the date of the publication of Messrs. Appolt's description, June 1858, the oven at Marquise, having worked regularly and without the least interruption since the time it was lighted on the 1st of September,

⁹ Bulletin de la Société de l'Industrie minérale, 1868-1869, xiv. 760 *et seq.*

¹ In an experiment on the small scale

in the laboratory, I find that when water is added to coal-slack the bulk of the latter is not increased.

1857, yielded the following results. Each compartment contained from 1350 to 1400 kilogrammes, that is, somewhat less than $1\frac{1}{2}$ ton of coal (1 ton = 20 cwt. of 112 lbs.). The coking was completely effected in the course of twenty-four hours. The workmen, it is asserted, suffered not the slightest inconvenience in the operations of charging and drawing, which took place in the day-time. The service of four men was required. Belgian caking coal gave from 80 to 82 per cent. of coke,² and English caking coal from 72 to 73 per cent. This yield is stated to be from 10 to 12 per cent. greater than that of ordinary ovens. Mixtures of non-caking and caking coals in different proportions also gave good results. The first experimental oven was erected at St. Avold, Department of the Moselle, by which the correctness of the principles of the method was established. Another larger experimental oven was subsequently built in the centre of the Saarbrück coal-field in Prussia; and although it did not possess several of the contrivances which have since been adopted, yet the result was pronounced satisfactory. An oven had been previously erected at Rivede-Gier in 1856, and continued at work regularly during several months, by which the maximum yield and solidity of construction were established; but it was afterwards discontinued, as the labour was found too expensive, from there being only six compartments. The coke produced at Marquise was used in the iron-smelting furnaces of that establishment, and was admitted to be of very good quality—hard, dense, close-grained, and possessing all the characters of good coke for metallurgical purposes. It was demonstrated that the quantity of gas evolved during coking was far more than sufficient to effect carbonization and to maintain the heat of the oven at the proper degree, so that the excess of gas might be advantageously applied to raising steam, etc. Under ordinary circumstances the cost of erection of an oven like that at Marquise may be estimated at from 14,000 to 15,000 francs—that is, from £560 to £600.

REMARKS ON THE APPOLT OVEN.—This oven differs much in construction from most other coke-ovens, and appears completely to fulfil the conditions of a close vessel or retort. Although it certainly is a costly structure, yet according to the inventors the cost in proportion to yield is less than in any other kind of coke-oven. Now it has been previously stated that the non-caking Thick-coal of South Staffordshire will cake and produce a solid coherent coke, provided it be rapidly exposed to a high temperature in a perfectly close vessel; and a prodigious amount of the fine slack of such coal has either been wasted, or left in the pits because it could not be raised with profit. It may be impossible to imitate on the large scale the conditions of the experiment in a crucible described at p. 309, and to heat rapidly a large mass of slack to bright redness; but of all the coke-ovens known to the Author that on the Appolt system seems to him to be one of the most favourable to the solution of the problem.

² This statement cannot be regarded as satisfactory without a knowledge of the composition of the coke; for the question might be raised, whether the carbonization of the coal had been thoroughly effected in the Appolt oven.

Mr. Menelaus has, however, informed the Author (June 1873) that some years ago he saw the Appolt ovens at work near Saarbrück ; and that the late M. de Wendel, to whom they belonged, and who was an excellent judge of coke-ovens, did not, at least at the time of Mr. Menelaus' visit, see any great merit in Appolt's scheme.

A description of Coppée's coke-oven, which should immediately follow that of Appolt, will be found in the Appendix at the end of this volume. This is due to the fact that the Author was unable to procure a satisfactory description and drawings of the oven in time for insertion in this place.

DAVIS' BREEZE-OVEN.

A patent was obtained for this oven, in 1856, by Mr. Joseph Davis, of Birmingham, under the title of "a new or improved method of

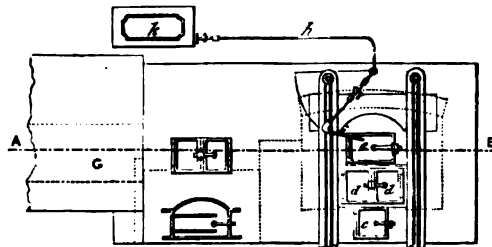


Fig. 89. Davis' breeze-oven. Elevation.

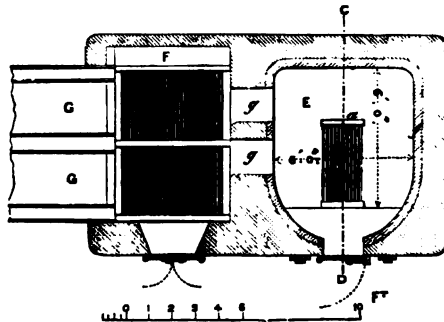


Fig. 90. Davis' breeze-oven. Horizontal section on the line A B, fig. 89.

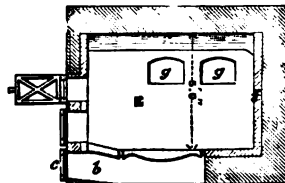


Fig. 91. Davis' breeze-oven. Vertical section on the line C D, fig. 90.

manufacturing the small coke, commonly called breezes, which said method of manufacture economizes heat, and effects the suppression or

partial suppression of smoke." ¹ Many of these ovens were in operation in Birmingham and the vicinity when the first edition of this volume appeared. I inspected one in 1860 at the Swan Foundry, Oldbury, belonging to Messrs. Taylor and Ensor, to whom I am indebted for the drawings from which the woodcuts, figs. 89-91, were made.

The oven consists of a chamber, *e*, lined with fire-brick; the side walls are vertical, and gradually approximate towards the opening in front; the wall at the back is also vertical; the roof is arched; the floor is flat, except the front part, which slopes inwards; in the floor is a grate, *a*, below which is an ash-pit, *b*, provided with a cast-iron door, *c*; the front is closed by the cast-iron doors, *d d*, and *e*. At the upper part of the side wall on the left are two openings, *g g*, communicating with a contiguous fire-place, *f*, from which the flame passes through the tubes, *o o*, of a steam-engine boiler. There is a cistern, *k*, filled with water, which may be conveyed through the iron pipe, *h*, and injected into the oven from a series of holes in the movable transverse pipe, *i*. The non-caking Thick-coal slack of South Staffordshire is treated in this oven. The slack is screened, and the finer part is burnt on the grate, *f*, adjoining the boiler, while the remainder is converted into "breeze" in the oven above described.

The process is conducted as follows:—Fire is lighted on the grate of the oven, the ash-pit door being open and the doors above closed; and when a considerable mass of incandescent fuel has accumulated, the ash-pit door is closed, and continues so until the end of the operation. Slack is then thrown into the oven, and spread as evenly as possible, and the doors are again closed. A copious evolution of inflammable gas is produced, which takes fire, and continues to burn by means of the air which finds its way through crevices around the sides of the doors in front. When the coal last thrown in has yielded its gas, and flame has ceased to be evolved in a sensible degree, a fresh supply of slack is thrown in, and so on at intervals until the oven has become filled as far as practicable. The coke is then extinguished by injecting water into the oven through the uppermost door in front, after which it is immediately withdrawn through the middle door. During this period it is necessary to burn some of the larger slack on the adjoining grate, in order to keep up the production of steam in the boiler.

The breeze which I saw thus produced had a brilliant silvery lustre. Mr. Ensor informed me that in one week this oven will produce from an amount of slack costing 30 shillings breeze of the value of from 50 to 55 shillings. The breeze is in request for smiths' fires. The patentee at the time of my visit stated that he would contract to erect an oven like that described for the sum of £50, making no further claim for the use of his process.

In 1847 a patent was granted to G. A. Michaut for the "pro-

¹ Specification, A.D. 1856, No. 1424.

duction and application of heat, and manufacture of coke," which appears to me very closely to resemble, if it be not identical with, that of Mr. Davis.²

SIEMENS' REGENERATIVE GAS- AND BREEZE-OVEN.

For the description and drawings of this oven, I am indebted to the inventor, Mr. C. W. Siemens.

The regenerative gas- and breeze-oven is a form of gas-producer, which differs from those generally used in connection with Siemens' regenerative gas-furnaces in that it not only produces the combustible gases for the supply of the furnace, but also furnishes breeze or light coke for the use of the smith. The ordinary form of gas-producer will be subsequently described in this volume, together with the regenerative furnace.

The word accumulative seems to me more suitable than regenerative. There is no regeneration of heat, but merely abstraction of some of the heat from the gaseous products of combustion, which would otherwise be carried off through the chimney and lost, and the restoration of that heat to the furnace.

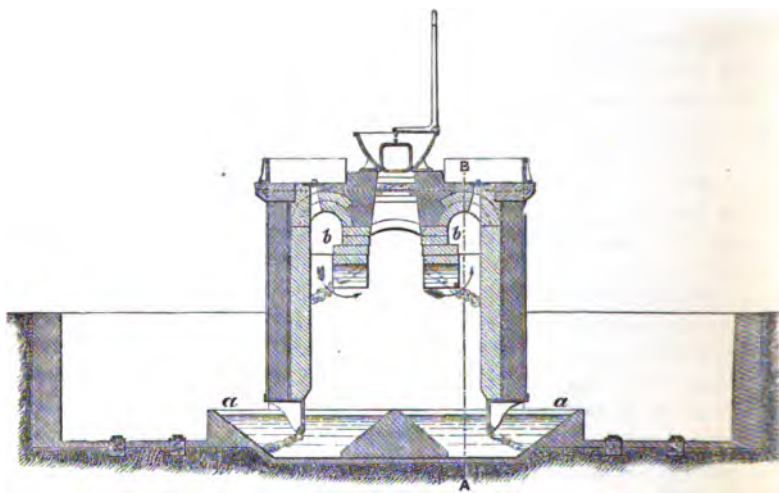


Fig. 92. Siemens' regenerative gas- and breeze-oven. Transverse section through the chamber on the line CDEF, fig. 94. The lighter sectional shading in this and the following woodcuts indicates fire-brick.

This breeze-oven is intended, like Davis' breeze-oven, to produce from the non-caking Thick-coal slack of South Staffordshire a hard bright breeze, well adapted for smiths' fires, and to economize the heat and gas generated. Unlike Davis' breeze-oven, it continues in operation without intermission. The construction of the oven is shown in figs. 92 to 95; the oven consists of a chamber lined with

² Specification, A.D. 1847, No. 11,997.

fire-brick, the upper part of which is divided into three parts by two flat arches running longitudinally from end to end: at one end of the chamber are two regenerators, which communicate with the side spaces, *bb*.

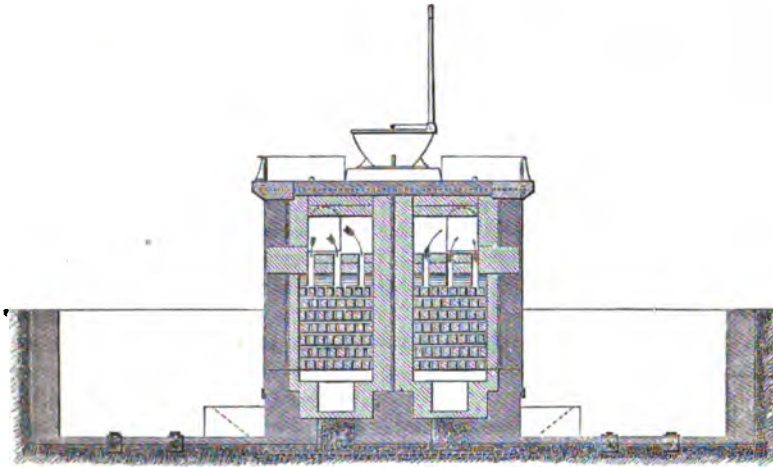


Fig. 93. Siemens' regenerative gas- and breeze-oven. Transverse section through the two regenerators on the line *a b*, fig. 94.

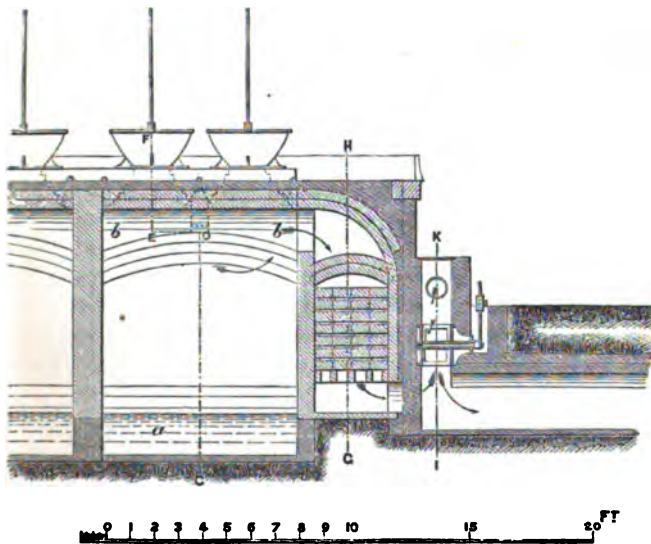


Fig. 94. Siemens' regenerative gas- and breeze-oven. Longitudinal section on the line *a b*, fig. 92.

The side walls of the oven are supported below by strong cast-iron bearers, the lower edges of which dip into a trough of water, *aa*, lined with sheet-iron to prevent leakage. The walls of the oven are for the most part built double, as shown in figs. 92 and 93, with

a layer of sand in the middle to assist in retaining the heat, and to prevent the escape of gas by filling up any cracks in the brick-work.

The coal-slack is supplied at intervals through the two cast-iron hoppers at the top, and fills the whole chamber with the exception of the two side spaces, *bb*, figs. 92 and 94. It is burnt by a current of air, which, entering through the tube, *c*, fig. 95, passes in the direction shown by the arrows, up through one regenerator into the oven, and across the latter, under the two longitudinal arches, *through* the mass

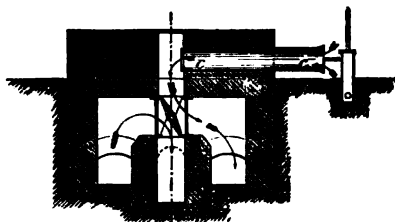


Fig. 95. Siemens' regenerative gas- and breeze-oven. Section through the reversing valve on the line *i k*, fig. 94.

of slack: the combustible gas produced passes down through the other regenerator, depositing successively the greater part of its heat, and thence escapes in a cooled state into the gas-flue, which carries it to the furnace. When the second regenerator is sufficiently heated by the descending current of gas, the direction of the draught through the oven is reversed by the valve

shown in figs. 94 and 95, and the air passing up through the hot regenerator enters the oven at a high temperature, while the current of gas passes down through the first regenerator and reheats it. The air is forced into the oven by a steam-jet at the entrance to the tube, *c*, fig. 95: this method of creating a draught has the advantages of increasing the production of gas by the action of the steam on the red-hot fuel, and of returning more heat to the oven; for the air which is required to support combustion is not by itself sufficient in quantity to take up all the heat which the gas loses in passing through the regenerator. The breeze produced is raked out at intervals at each side of the oven from under the cast-iron bearers, more coal-slack being put in at the top. There are three small stoppered holes at each side of the top of the oven, through which an iron bar may be put to stir or break up the mass of fuel, and a row of holes, about a foot apart, in the cast-iron bearers at the bottom of the oven, to allow any large piece of coke to be broken up if it cannot be easily got out whole.

These breeze-ovens may be conveniently built in pairs, as shown in fig. 94, and a number of such pairs built together may be arranged in rows, with a small tramway (shown in figs. 92 and 93) between each two rows.

Some ovens of this description were erected about the year 1861 at Messrs. James Russel and Sons' Crown Tube-works, Wednesbury, Staffordshire. One such oven has been found to produce, besides breeze, as much gas as five or six ordinary producers.

It is important that the main gas-flue leading to the furnaces should contain an excess of pressure, however slight, above that of the atmosphere, in order to prevent any inward draughts of air through cre-

vices, which would cause partial combustion of the gas and diminish its heating power in the furnace, besides causing a deposit of soot in the flues. It is therefore necessary to deliver the gas into the furnace, without depending upon a chimney-draught for that purpose. In the gas- and breeze-oven this is done by means of the blast of air caused by the *steam-jet*, as above mentioned.

MINERAL-CHARCOAL.

At the Great Exhibition of 1851, the late Mr. Rogers, of Abercarn, exhibited a specimen of what he termed *charred coal*, but which he afterward designated *mineral-charcoal*. It is a light, porous, almost pumice-like coke, which he recommended as a substitute for wood-charcoal in the manufacture of tin-plate.

At the time mentioned above, Mr. Rogers refused to divulge the process of its preparation; but in 1858 he published the following account of it at a meeting of the South Wales Institute of Engineers. The coal is first reduced to "small," and washed by any of the ordinary means; it is then spread in its wet state over the bottom of a reverberatory furnace to the depth of about four inches, the bottom of the furnace having been previously heated to redness. When the coal is thrown in, much gas is evolved, and great ebullition occurs. A light spongy mass is thus produced, which is turned over in the furnace, and drawn out in about an hour and a half. Water is then freely sprinkled over the mass until the smell of sulphuretted hydrogen ceases. In preparing mineral-charcoal he availed himself of the floor of an ordinary coke-oven immediately after the charge had been drawn, and while it was still red-hot.³

A short time after the preceding description was published, Mr. Thomas, formerly blast-furnace manager at the Pontypool Ironworks, read a paper before the same Institute on the manufacture of iron with *mineral-charcoal*. After preparing and working a large quantity of this *new fuel*, he makes the rather startling announcement, "that it makes much better iron, for the manufacture of tin-plate, than that produced from the puddling process, or where wood-charcoal is employed as a refining fuel."⁴ He further states,—“The iron made from the finer's lump, and after rolling, differs in no respect from iron made with wood-charcoal; it is quite as strong and very clean.” As much work may be done with five shillings' worth of mineral-charcoal as with twenty-four shillings' worth of wood-charcoal. The mineral-charcoal which Mr. Thomas used in his experiments was produced from a seam of coal locally termed the "wing seam," which has always been celebrated for its superior quality as an iron-making coal. The following analysis of this coal was made by Mr. W. Ratcliffe in Mr. Rogers' laboratory:—

³ Proceedings of the South Wales Institute of Engineers, Merthyr Tydvil, Jan. 1858, i. 19.
⁴ Idem, April 1858, i. 101.

COMPOSITION, PER CENT., OF THE WING SEAM COAL, AND OF ITS ASH.

| Coal. | | Ash. | |
|----------------|--------|-------------------------|--------|
| Carbon | 81·13 | Silica | 25·32 |
| Hydrogen | 4·72 | Alumina | 33·45 |
| Nitrogen | 1·03 | Sesquioxide of iron ... | 11·39 |
| Oxygen | 10·12 | Lime | 16·06 |
| Sulphur | trace | Magnesia | 6·60 |
| Ash | 3·00 | Potash | 0·96 |
| | | Soda | trace |
| | 100·00 | Sulphuric acid | 4·81 |
| | | Phosphoric acid | 0·81 |
| | | Loss | 0·60 |
| | | | 100·00 |

After a week's trial Mr. Thomas found the yield of mineral-charcoal from this coal to be nearly 78·3 per cent.; whereas coal from the same seam, when subjected to the ordinary process of coking in ovens during forty-eight hours, yielded about 64 per cent. It is to be regretted that an analysis of the mineral-charcoal has not been published; for without a knowledge of its composition the figures of Mr. Thomas just cited lose much of their value.

Mr. Rogers, in announcing the preparation of mineral-charcoal as a novel invention in 1851, could not have been aware of the fact that a process identical with that which he has described for its preparation had certainly been published in this country in 1826, and again in 1841, as will appear from the following extract:—

“When coke is required to be more of the nature of charcoal, the process is conducted in a different manner. The small coal is then thrown into a large receptacle, similar to a baker's oven, previously brought to a red-heat. Here the door is kept constantly open, because the heat of the oven is of itself sufficient to dissipate all the bitumen of the coals, the disengagement of which is promoted by frequently stirring the coal with a long iron rake. The coke from these ovens, though made with the same kind of coal, is very different from that produced by the former operation (i.e. of coking, as practised in ovens of the Duke of Norfolk's colliery, and described at p. 431); this being intensely black, very porous, and as light as pumice-stone.”⁵

PREPARATION OF COKE FROM THE SLACK OF NON-CAKING COAL.

The meaning of the word non-caking has been previously explained (see p. 306), and in illustration it was stated that, when a mixture of the powder of that kind of coal and of a caking coal is heated to redness in a close vessel, such as a retort or covered crucible, a firmly coherent coke is produced; whereas the powder of the same coal,

⁵ Parkes' Chemical Catechism, 12th edition, 1826, p. 454. This description was again published nearly verbatim in the History and Description of Fossil Fuel, the Collieries, and the Coal Trade of Great Britain. By the Author of the “Treatise on Manufactures in Metal” in the Cabinet Cyclopædia. 2nd ed. London, 1841, p. 413.

when heated *per se* in the same manner, either does not agglomerate in a sensible degree or at most yields a residue so feebly coherent that it may be easily crushed between the fingers. The fine slack of such coal was for a long time a waste material. It could not be burnt on any grate then in use, because much of it would fall into the ash-pit, even though the distance between the fire-bars was greatly reduced; and if it had been possible to construct a grate to retain it, a layer of it only an inch or two in thickness would have effectually prevented the passage through it of sufficient air to support combustion. No attempt was made to render it serviceable as fuel, probably because coal in lumps suitable for burning was abundant and so cheap that it was not thought worth while to direct attention to the possibility of utilizing slack; and, accordingly, enormous quantities of such slack have been left in the pits or burnt designedly on pit banks, though every ton of it was capable of evolving as much heat as a ton of the same coal in lumps. But in recent years, owing doubtless to the steady increase in the consumption and cost of coal, the problem of the utilization of the fine slack of non-caking coal has been much considered, and hitherto the only practicable solution of that problem has been found to be the intermixture of a cohesive material with the slack, to agglomerate it into blocks fit either for immediate use or for conversion into coherent coke. In the first case the product is commonly known by the name of "patent fuel," which is chiefly used for steam navigation. Carbonaceous substances have been generally used for effecting agglomeration, but a few saline or earthy matters, so called, have also been proposed with the same object.

As non-caking coal rich in carbon yields a much greater weight of carbonaceous residue than non-caking coal rich in oxygen, it is obvious that, *ceteris paribus*, the slack of the former is a more valuable article for the manufacture of coke by an agglomerative process than that of the latter.

In 1854 a patent was taken out by Mr. Dawson for "converting small coal or coal-dust, or small coal and coke, into blocks of fuel."⁶ The dust, moistened with water, is pressed into a cast-iron box having a tightly-fitting cover, and the whole is exposed to a temperature ranging from 300° to 700° Fahr. An experimental oven was erected near Whitechapel, which I saw. At my request, Mr. Dawson operated upon some of the Thick-coal slack from West Bromwich, with which I supplied him; but the result was unsuccessful.

PREPARATION OF COKE FROM A MIXTURE OF NON-CAKING AND CAKING COAL OR COAL-SLACK.

In 1850 Mr. James Palmer Budd, of Ystalyfera, near Swansea, obtained a patent⁷ for the manufacture of coke by heating intimate mixtures of non-caking and caking coal, the more strongly caking the

⁶ Specification, A.D. 1854, No. 3.

⁷ Specification, A.D. 1850, No. 13,121.

better. The two kinds of coal may be ground together in a pug-mill, similar to that used for grinding mortar, or rolls may be employed for the purpose, either with or without grooves. No particular method of coking is claimed; nor are definite quantities of the two kinds of coal prescribed, as the proportion of caking coal will necessarily depend on the degree of its caking quality. It is, however, recommended that in the first instance trial should be made of a mixture of equal weights of the two kinds of coal; and if a sound coke be not thus obtained, the proportion of caking coal must be increased until coke of suitable quality is produced. Every variety of non-caking coal, inclusive of anthracite, is suitable for this process.

According to Mr. Budd, it is not so important to crush the lumps of the caking coal as those of the non-caking coal; but this has not been confirmed by the experience of others. Thus, in reference to the preparation of coke from a mixture of anthracite and caking coal, Vériot and Till-Appolt assert that "the finer the caking coal is ground the less of it will be required to agglomerate and solder the particles of anthracite together; and that they have manufactured firmly coherent coke from a mixture of 4 parts of moistened anthracite in particles as large as common peas, or a quarter of that size, and 1 part of caking coal very finely divided. The caking coal attaches itself merely like a layer of paint to the surface of the grains of moistened anthracite; and it may be conceived that the aggregate of the surfaces to be thus coated would be too great if the grains of anthracite should be too small. These grains remain inert during carbonization, and shine distinctly like little stars in the coke produced without showing the slightest trace of fusion on their surface. In order to produce firmly coherent coke of this kind, and at the same time to economize caking coal, the two kinds of coal should be ground separately, and afterwards mixed in the proportions above stated. If both be reduced indiscriminately to the same degree of fineness, as in the case of their intermixture before trituration, good useful coke cannot be produced unless the caking coal forms one-third of the whole mixture."⁸

In 1856 Mr. Budd's process was again patented not less than three times: the first time by Mr. A. Perpigna;⁹ the second time by Mr. R. A. Brooman, who asserts that the distinctive feature of his invention is "to reduce the materials to a powder before mixing them, instead of first combining them and then reducing them to powder;"¹ and the third time by Mr. L. S. Magnus.² In 1858 a provisional specification of the same process was filed by Messrs. Yelverton and Bowen.³

⁸ De la Carbonisation des Houilles maigres. Bulletin de la Société de l'Industrie minière, 1868-1869, xiv. 758.

⁹ Specification, A.D. 1856, No. 873.

¹ Specification, A.D. 1856, No. 1828.

² Specification, A.D. 1856, No. 2033.

³ Specification, A.D. 1858, No. 305.

PREPARATION OF COKE BY ADMIXTURE OF NON-CAKING COAL-SLACK
WITH PITCH OR TAR.

In 1854 Mr. John Bethell obtained a patent for the manufacture of coke by heating pitch, or pitch mixed with coal.⁴ Coal-tar pitch is preferred on account of its cheapness. It is broken into small pieces, and well mixed with the coal in the proportion of 1 ton to 4 tons of coal, and the mixture is converted into coke by burning it either in coke-ovens or in piles. The mode of action of pitch in effecting agglomeration has been previously explained (see p. 306). In the provisional specification no claim is made in reference to the agglomeration of coke-dust or small pieces of coke by this process; whereas in the specification itself such a claim is entered. Several years before the date of this patent I had employed with complete success gas-tar intermixed with anthracite powder, or the powder of gas-retort carbon, in the preparation of carbon crucibles of large size. In 1858 Mr. Bethell procured a second patent for making large coke of good quality, by heating in a common coke-oven a mixture of breeze (coke-dust, of which large quantities may be obtained at a low price at gasworks) and coal-tar, or coal-tar pitch.⁵ As this invention is claimed in the specification of the first patent, except the use of coal-tar, the reason of its introduction into that of the second patent is not obvious. In 1859 I had the opportunity of witnessing Bethell's process in operation at Llanelly, South Wales. The mixture employed consisted of crushed anthracite and coal-tar pitch. The anthracite was previously washed in a kind of jiggling machine to free it as far as practicable from shale, etc. The men appeared to suffer much from irritation of the eyes and skin, especially about the face, caused by the fine particles of pitch.

Bethell's process has been re-patented more than once. It was announced in 1857 that coke made of a mixture of 4 parts of anthracite and 1 part of caking coal had been tried with success at ironworks at Commentry, in France.⁶ In 1857 Mr. William Cory obtained a patent for the manufacture of coke by heating the slack of non-caking coal and anthracite with gas-tar or pitch, of which, if the mixture is intimate, the proportion of one-fifth or one-tenth of the weight of the coal will suffice.⁷ At the end of the same year Bethell's process was again patented by Carl Buhning, who, in addition to pitch, claimed the use of asphalt, sugar, wax, or any other bitumen, rosin, or gum, or any mixture of these materials. The claim, as is usual in such cases, is made as comprehensive as possible, and embraces "carbonized animal or vegetable materials," "such as coke, charcoal, boghead ash, peat-coal, wood, bone, dried blood, peat, or

⁴ Specification, A.D. 1854, No. 80. This patent expired, from non-payment of stamp-duty, some time after it was granted.

⁵ Specification, A.D. 1858, No. 159.

⁶ Mining Journal, Feb. 21, 1867. The process is associated with the name of Tardieu, but on what grounds I am ignorant.

⁷ Specification, A.D. 1857, No. 1174.

any such material which by the action of heat may be carbonized."¹ During several years previously, in the Metallurgical Laboratory of the Royal School of Mines, crucibles had been lined with lamp-black or charcoal mixed with treacle or starch, substances which appear to have eluded the grasp of this patentee. In 1858 a provisional specification was filed by Mr. J. T. Smith for "the manufacture of coke from small coal, or the small coal called breezes," by admixture with tar, or tar deprived of its naphtha, or a portion of its oil.²

In 1860 Mr. Jabez Church obtained a patent for Bethell's process, with the addition of lime or carbonate of lime in the proportion of 25 lbs. of slaked lime to 140 lbs. of asphalt, or pitch of coal-tar, and 1 ton of coal. He also claims the use of coke, breezes, or cinders, ground or unground, except that he first washes these substances "to take out the sulphur compounds of iron, and other impurities which they may contain."¹ (1) For what reason lime is employed, we are not informed. However, a patent had been previously obtained by Dr. Hermann Bleibtreu in 1857 for the manufacture of coke for metallurgical purposes from an intermixture of small or crushed coal and powdered limestone, chalk, burnt lime, or other calcareous substance, with a view "to prevent the impurities of coal, such as sulphur, silica, alumina, phosphorus, etc., from exercising an injurious influence upon the products of metallurgical processes."² This lime coke, it is stated, is applicable to all purposes for which common coke may be used; "but it will be found most valuable for the manufacture of iron and steel, and will be the means of producing a quality of iron far superior to that produced by the use of coal or common coke, or perhaps nearly if not quite equal to charcoal iron." Mr. Jabez Church, acting on the principle of killing two birds with one stone, has combined in his single patent the two processes previously patented by Bethell and Bleibtreu. Vériot and Till-Appolt state that they have prepared from the coal of the Sarre basin hard and solid coke, which contained as much as 12 per cent. of caustic lime, besides the earthy matter derived from the coal; and that this kind of coke burns very well, and facilitates the passage of the sulphur of the coal in the state of sulphide of calcium into blast-furnace slags. In the manufacture of such coke caustic lime is preferable to limestone.³ It may be stated that in 1853 Mr. T. S. Prideaux obtained a patent for "Improvements in the manufacture of iron," in which he claimed the impregnation of coke with various alkaline substances. The coke made from coal in retorts, he directs, is to be cooled by throwing upon it lime-water mixed either with common salt or carbonate of soda in the proportion of 2 per cent. of the weight of the coke; but, he adds, any substance "electropositive towards iron" may be used, namely, potassium, sodium, barium, strontium, etc.⁴

¹ Specification, A.D. 1857, No. 3194.

² Specification, A.D. 1858, No. 1614.

³ Specification, A.D. 1860, No. 784.

⁴ Specification, A.D. 1857, No. 1528.

⁵ Bulletin de la Société de l'Industrie

minérale, 1868-1869, xiv. 759.

⁴ Abridgments of the Specifications relating to the Manufacture of Iron and Steel, 1858, p. 130.

AGGLOMERATION OF COAL-SLACK OR COKE-DUST BY ADMIXTURE WITH
FARINACEOUS MATTER (BARKER'S PATENT FUEL).

In 1864 and 1865 respectively, patents were granted to Mr. David Barker for "Improvements in the Manufacture of Artificial Fuel."⁵ In the second patent, which appears to be merely a slight enlargement of the first, the invention is stated to relate "to certain improvements in the treatment of coal, coke, peat, charcoal, and tan, whereby those substances can be utilized when in a state of powder or minute division, and a serviceable fuel formed thereof, such treatment being also applicable for like purposes to sawdust and woody fibre in a state of division." Cohesion between the particles of the substance to be agglomerated is effected by means of mucilage "composed of any farinaceous substance, consisting principally of fecula or starch, and from which the gluten has been removed; or yeast, or any vegetable substance capable of being formed into a mucilage, and destitute of gluten, may be used in place of or together with the farina." With regard to the employment of farinaceous substances in the preparation of artificial fuel, the patentee remarks that he is well aware "that the same have been so used; but for the formation of the mucilage hereinbefore mentioned, I employ farina from which the gluten has been removed, and which consists entirely, or almost entirely, of fecula or starch, the mucilage obtained being free from a tendency to decompose." The patentee prefers and adopts the following method of preparing his mucilage:—"One pound of fecula (say potato farina) is mixed with four pints of water, four ounces of sulphate of iron or other salt possessing similar or analogous properties; or, in lieu thereof, four ounces of tannic acid or other acid possessing similar or analogous properties, are dissolved in about twelve pints of water, then mixed with the farina and water, a mucilaginous substance being thereby formed." The mucilage is "added to the powdered coal in the proportion of two ounces of the former to 1 pound of the latter, and the mass having been thoroughly mixed and incorporated, and [*sic, ? is*] afterwards formed into blocks of any desired size and form, and dried for use, any suitable machinery or apparatus being employed for such purposes." The patentee claims that "the fuel thus compounded is in a very considerable degree, and especially if it has been subjected to a high pressure, impervious to moisture, and . . . entirely free from smell, whilst for furnace purposes it has the valuable property of exercising no injurious effect upon the fire-bars or boiler plates." As regards the last point, however, he admits that the fuel produced possesses "all the qualities of the articles employed [in its preparation] when existing in a more marketable condition." Neither of Barker's patents contains any claim to make coke from coal-slack or dust agglomerated in the manner described.

Mr. Alexander Bassett read a paper⁶ before the South Wales

⁵ Specifications, A.D. 1864, No. 1842; Small Coal, by Alexander Bassett, M.I.C.E.,
A.D. 1865, No. 1547. Past President of the South Wales In-

⁶ On Patent Fuel, or the Utilization of
stitute of Engineers. Newport, 1867.

Institute of Engineers, in 1867, on the subject of Barker's artificial fuel, from which I have extracted the following particulars:—The process is carried on by the London Patent Coal Company (Limited), at Northfleet, Kent. The small coal passes through a disintegrator, which reduces it to one uniform size; it afterwards enters a pug-mill together with a continuous and regular supply of the mucilage, "the mixing of which will be accomplished by very simple mechanical means." The material is then moulded into blocks, which are afterwards thoroughly dried by from 9 to 12 hours' heating in ovens, the temperature of which should not be less than from 250° to 300° (? Fahr.). The cost of manufacturing this fuel, inclusive of the cost of the mucilage and acid, but exclusive of that of the coal-slack and of the royalty on the patent right, is estimated at 2s. 6d. per ton. Mr. Bassett has tabulated the results of various comparative trials under steam-boilers of various coals and their slack agglomerated by the process in question, from which it appears that the evaporative power and useful effect in raising steam are nearly the same in both.

Imperviousness to moisture is undoubtedly very important in cases where the fuel is liable to be exposed to the weather, as on the tenders of locomotives; and, according to Mr. Bassett, the cheapest and most simple plan of rendering the blocks of fuel impervious is to dip them, immediately after they have left the drying ovens, into coal-tar oil: they become thoroughly dry in a few minutes after dipping. This process is termed *waterproofing*.

I have tried such blocks, supplied to me by Mr. Bassett, in an ordinary domestic fire-place, and found them to burn steadily and produce sufficient heat: they were made from the waste steam-coal slack of South Wales, of which there are large accumulations.

The use of farinaceous matter as a cementing material for coal-slack is of old date: thus, Mr. W. J. Prim, a native of Kilkenny, informs me that it was the universal practice in Ireland, previously to the potato failure, to boil potatoes unpeeled, and that the stiff pulp obtained by pounding their skins with the addition of a little water was mixed with coal-dust and sufficient water to make a mixture about the consistency of stiff mortar. The mass was then well tempered, partly with a shovel and also by treading under foot, after which it was formed by hand into oval-shaped balls, which were stacked in a dry cellar for use in domestic fire-places.

QUALITY OF COKE PRODUCED BY DIFFERENT METHODS.

According to Mr. R. Williams, of the Pontypool Ironworks, "yard-coke," which is made by coking in open pyramidal heaps and from lump-coal only, is not so hard, and will not bear as much *burden* of ore in the blast-furnace, as oven-coke; and in the making of yard-coke much coal is burned to waste. On the other hand, yard-coke has the advantage over oven-coke when working with cold-blast; in this case it burns better before the *tweyers* than the

more dense oven-coke. Mr. Richards, manager of the Ebbw Vale Ironworks, informs me (November 1874) that yard-coke is no longer made at the latter works. Coke from retorts, in which coal had been distilled for tar, has been used with success at Pontypool when working with cold-blast, in which case it has been found to answer better than oven-coke: it has also been used successfully in the *hollow-fire*.¹

DESULPHURIZATION OF COKE.

When coal is exposed to a red-heat, the bisulphide of iron or iron-pyrites which it contains is reduced to protosulphide, and, accordingly, this sulphide is present in coke. The sulphurous acid evolved from burning coke is due to oxidation of the sulphide by the oxygen of the atmosphere; and the escape of sulphuretted hydrogen occasioned by the action of water on incandescent coke is caused by the same sulphide, which at a high temperature decomposes water, with the liberation of that gas and the formation of oxide of iron. In certain metallurgical operations in which coke is employed as fuel, the presence of sulphide of iron in sensible quantity may produce very injurious effects. Iron-pyrites is frequently so intimately mixed with coal that it is impossible to separate it by mechanical means; but, were it possible to do so, it would be necessary in the first instance to crush the coal to powder, so that only caking coal could be operated upon; unless, in the case of non-caking coal like that of South Staffordshire, recourse were had to the process of mixing it with the slack of caking coal, or with pitch or some other similar matter; for there is no practical method known at present by which the powder of this coal can otherwise be made to cohere by coking.

Various processes have been proposed to effect the partial or complete removal of the sulphur existing in the state of sulphide of iron in coke; but not one, so far as the Author is aware, has proved sufficiently satisfactory and economical to have been adopted in practice. Those which will be here noticed are founded on the following principles:—

- I. Heating coke to redness in a current of steam.
- II. Heating coke to redness in a current of atmospheric air under ordinary barometric pressure.
- III. Heating coke to a lower temperature than redness in a current of compressed atmospheric air.
- IV. Coking coal in admixture with common salt.

I. DESULPHURIZATION OF COKE BY STEAM.

An impression has long prevailed that, when red-hot coke is extinguished with water, it loses a considerable amount of sulphur, and is

¹ For an explanation of the terms used in this paragraph, relating to iron-smelting, the reader is referred to the volume on Iron and Steel by the Author.

thereby improved in quality; but that impression is derived from the odour of sulphuretted hydrogen which accompanies such extinction, and which may greatly mislead, because an exceedingly small quantity of that gas produces a powerful effect upon the organs of smell. Scheerer has published the following result of an experiment made to determine the proportion of sulphur which may be eliminated from coke by the action of a current of steam.² High-pressure steam was passed into a coke-oven containing red-hot coke, ready to be drawn; but, previously, some of the coke was taken out for analysis, and found to contain 0.71 per cent. of sulphur. The coke, after having been during some time exposed to the action of steam, was found to retain 0.28 per cent. of sulphur; so that a reduction in the quantity of sulphur in the ratio of 1.0 to 0.4 had occurred. Many years previously Nordenskiöld introduced the practice of desulphurizing iron ores containing sulphide of iron, by subjecting them at a red-heat to the action of steam.

The application of steam to the desulphurization of coke has been patented in this country by Messrs. Claridge and Roper.³ They propose a coke-oven, having a false perforated bottom, underneath which, at any time during the process of coking, steam can be admitted and made to ascend through the stratum of coke above. In an oven of the same construction they also propose to introduce through the bottom, in aid of the process of coking, the waste-gases of iron-smelting furnaces.

It will be remembered that when steam is passed through red-hot coke, it is decomposed with the production of hydrogen and marsh-gas, carbonic oxide, and carbonic acid, and that consequently there must be considerable loss of carbon in Claridge and Roper's process.

When we reflect upon the physical state of coke, especially of that which is compact and comparatively free from porosity, it is difficult to conceive how there should be extensive contact between the steam and the sulphide of iron, which, to a considerable extent, must be enclosed in the substance of the coke. In the case of light and very porous cokes this contact would exist in a greater degree, yet it would nevertheless be far from sufficient to effect perfect desulphurization.

Since the publication of the foregoing remarks in 1861, the subject of the desulphurization of coke by steam has been experimentally investigated by M. Alf. Philippart, an engineer connected with the management of the blast-furnaces of the well-known ironworks of Cockerill and Company at Seraing, in Belgium; and his results are reported in a Prize Essay "On the Modes of Desulphurizing Coke," which appeared in 1871.⁴

Philippart states that the coke made in ovens at Seraing—which, in order to distinguish it from coke made in crucibles for the purpose

² Berg- und hüttenmännische Zeitung, 1854, xiii. 239.

³ Specification, A.D. 1858, No. 810.

⁴ Revue Universelle des Mines, de la Métallurgie, etc., 1871, xxviii. 261-318.

of experiment, is termed "industrial coke"—contained (after drying at 100° C.), on the average, 0·55 per cent. of sulphur, of which—

0·40 per cent. existed in the state of bisulphide of iron,
 0·10 " " " protosulphide of iron, and
 0·05 " " " sulphate, mainly of lime.

The proportions of the two sulphides of iron are shown in the formula—



Bisulphide of iron in notable proportion is also stated to have been found along with protosulphide in coke prepared by heating gradually from 60 to 70 grammes of finely pulverized coal in "hermetically" closed clay crucibles, during two hours, up to the melting-point of cast-iron.

Now, it has generally been concluded that in the operation of coking, the bisulphide of iron in coal is reduced to protosulphide, if not, indeed, partially to a still lower sulphide, $\text{Fe}^2\text{S} + 6\text{FeS}$ [idem]; and it can hardly be doubted that the temperature in the interior of an ordinary coke-oven is sufficiently high to effect such reduction, to say nothing of the action of carbon upon the sulphur of the pyrites, and the probability of its favouring the elimination of that element in the state of bisulphide of carbon. This conclusion is opposed to the results of Philippart stated above, and will hardly be abandoned until his results are confirmed by other chemical analysts.

Philippart subjected coke, consisting of particles between 2 and 3 millimetres in diameter, to a current of steam, using for his apparatus a glass combustion tube heated to redness. "Industrial coke" was thus operated upon during eight hours with the results shown in the following table:—

TABLE SHOWING THE PROPORTIONS OF SULPHUR AND ASH IN COKE BEFORE AND AFTER DESULPHURIZATION IN A CURRENT OF STEAM.

| State of combination of the Sulphur. | Per cent. of Sulphur. | |
|--------------------------------------|--------------------------|-------------------------|
| | Before Desulphurization. | After Desulphurization. |
| As sulphide | 0·575 | 0·450 |
| As sulphate | 0·050 | 0·040 |
| Total..... | 0·625 | 0·490 |
| Per cent. of ash in the coke | 9·50 | 7·50 |

It will be perceived that about 20 per cent. of the sulphur was evolved chiefly in the state of sulphuretted hydrogen. The number 7·50

representing the weight of ash after desulphurization is, doubtless, a typographical error, and should be 9·50; because the author shortly afterwards states that the percentage of ash was the same before and after exposure to steam in this experiment, and in two others on crucible-made coke. No trace of ash was perceived upon the particles of coke after their exposure to steam, whence it is inferred that none of the combustible part of the coal had been removed. But the evidence on which this inference rests is not conclusive. It certainly is not unreasonable to suppose that some of the steam would be decomposed by contact with red-hot carbon; and this point might easily and quickly have been decided by ascertaining whether any permanent gas, other than sulphuretted hydrogen or sulphurous acid, escaped along with the steam from the glass tube used in the experiments.

II. DESULPHURIZATION OF COKE BY ATMOSPHERIC OXYGEN UNDER ORDINARY PRESSURE.

Experiments have been made by Philippart on a small scale in the laboratory to ascertain whether it is possible to desulphurize coke by heating it in contact with atmospheric air, under ordinary barometric pressure, to a degree sufficient to convert the sulphur of the sulphide of iron contained in it into sulphurous acid, without at the same time oxidizing the carbon in sensible quantity; and, as might have been anticipated, the results were wholly unsatisfactory. The experiments were conducted at a temperature below a red-heat.

Philippart made an experiment of this kind upon industrial or oven-made coke, with the following results:⁵—

TABLE SHOWING THE PROPORTIONS OF SULPHUR AND ASH IN COKE BEFORE AND AFTER DESULPHURIZATION BY ATMOSPHERIC OXYGEN UNDER ORDINARY BAROMETRIC PRESSURE.

| State of combination of the Sulphur. | Per cent. of Sulphur. | |
|--------------------------------------|--------------------------|-------------------------|
| | Before Desulphurization. | After Desulphurization. |
| As sulphide..... | 0·475 | 0·300 |
| As sulphate..... | 0·075 | 0·550 |
| Total..... | 0·550 | 0·850 |
| Per cent. of ash in the coke | 13·25 | 24·75 |

⁵ Revue Universelle des Mines, de la Métallurgie, etc., 1871, xxviii. 283.

Hence, only 10 per cent. of the total sulphur was converted into sulphurous acid, and the loss of carbon by oxidation (calculated from the percentage of ash before and after the experiment) amounted to 55 per cent.

In two experiments on crucible-made coke better results were obtained: in one of these experiments, which lasted ten hours, coke containing 4.82 per cent. of sulphur in the state of sulphide and 0.08 per cent. in the state of sulphate was operated upon, and after the experiment was found to contain 1.10 per cent. of sulphur in the state of sulphide and 0.70 per cent. in the state of sulphate, showing that 72.50 per cent. of the total sulphur had been converted into sulphurous acid, since 27.50 per cent. of carbon had been lost by oxidation; while in the other experiment, which lasted twenty hours, coke containing 0.775 per cent. of sulphur in the state of sulphide and 0.05 per cent. in the state of sulphate was operated upon, and after the experiment was found to contain 0.60 per cent. of sulphur in the state of sulphide, and 0.125 per cent. in the state of sulphate, showing that 30 per cent. of the total sulphur had been converted into sulphurous acid, since 18 per cent. of carbon had been lost by oxidation.

It will be remarked that after the foregoing experiments there was a notable increase in the proportion of sulphur existing in the state of sulphate, due, it is alleged, to the formation of ferrous, if not also of some ferric, sulphate; and this is somewhat remarkable, as a temperature, which sufficed for the oxidation of so much carbon by atmospheric air, might be supposed to suffice for the oxidation of carbon by ferrous or ferric sulphate, with the reduction of these salts to sulphide of iron, and still more for the reduction of ferric to ferrous sulphate.

There will, I think, be a general agreement in the conclusion arrived at by Philippart, namely, "that in spite of the important desulphurization obtained in our laboratory trials, we do not believe that the roasting of the fuel with free access of air is susceptible of industrial application."

III. DESULPHURIZATION OF COKE BY ATMOSPHERIC OXYGEN UNDER INCREASED PRESSURE.*

MM. Grandidier and Rue, French engineers, have proposed to desulphurize coke by exposing it, when heated to a temperature varying between 250° C. and 300° C., to a current of atmospheric air condensed under a pressure of from three to four atmospheres; and they have described apparatus which they consider to be suitable for the purpose. They allege that by means of such compression, the air may be made to penetrate into the interior of a mass of coke, and to oxidize the protosulphide of iron contained in the latter, without acting in a sensible degree upon the carbon; that the protosulphide

* *Revue Universelle*, 1871, xxviii. 288 *et seq.*

of iron is changed first into ferrous sulphate, and afterwards, by the continued action of an excess of air, into basic ferric sulphate; and that this latter salt, being in the presence of the shale or silicate of alumina existing in the coke, is converted into sesquioxide of iron and sulphate of alumina, the silica becoming free. This reaction is, however, stated to be only partial, for much of the sulphur of the ferric sulphate is evolved in the state of sulphurous acid during the decomposition of that salt, as may be inferred from the odour of the gases which escape from the apparatus. After this treatment, the coke no longer contains any sulphur in the state of sulphide, and the little which it does retain is in the state of sulphate of alumina, a very soluble substance which may be washed out. If the washing were perfect, the whole of the sulphate of alumina would be removed; but the proportion of it, which may remain, produces no injurious effect in metallurgical operations, as it passes totally into the slags. Hence it follows that the coke thus operated upon should yield less ash than it did originally. We are informed that "the most minute precautions have been taken to detect even the smallest traces of sulphur in the desulphurized coke, and that uniformly not the slightest indication of its presence could be perceived." The coke thus desulphurized is said to have "entirely different properties from those of common coke," to be more porous and in consequence more combustible, and to have a higher calorific power than the latter.

The preceding statements in favour of the process of MM. Grandidier and Rue are very strong, and might have been captivating if they had been supported by satisfactory experimental evidence. But, in addition to obvious reasons for doubting their accuracy on theoretical grounds, they have been put to the test of experiment on the large scale at John Cockerill's works at Seraing, as well as at those of MM. Braconier at Tilleur, and have been proved to be erroneous. The following report of the results of the experiments made at those works has been published by Philippart:—

The apparatus used consisted of a cylinder (the nature of the substance of which is not mentioned) fixed horizontally and heated externally along its whole length, and provided at each end with a tight-fitting cover, kept in position by a screw arrangement, like that of a common gas-retort, I presume. Its internal diameter was 1·6 metre, its length 3·5 metres, and its capacity 7 cubic metres. Two safety-valves of suitable dimensions were fixed in the upper part of the cylinder, and weighted so as to keep up the desired pressure within it. The coke was introduced into the cylinder in cylindrical waggons, running on rails fixed within and near the lowest part of the cylinder. These waggons were formed of horizontal bars of iron, set at some distance apart from each other, and fixed at their ends in two discs of sheet-iron, which moreover had holes in them: the waggons were made as large as the diameter of the cylinder permitted.

At Braconier's works, 3 cubic metres or 1350 kilogrammes of coke made from washed coal were operated upon at a time, and air was

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injected under a pressure of two atmospheres.¹ In the following table are shown the proportions of sulphur in coke (after desiccation at 100° C.) from the same oven before and after desulphurization :—

TABLE SHOWING THE PROPORTIONS OF SULPHUR AND ASH IN COKE BEFORE AND AFTER DESULPHURIZATION BY ATMOSPHERIC OXYGEN UNDER A PRESSURE OF TWO ATMOSPHERES.

| State of combination of the Sulphur. | Per cent. of Sulphur. | |
|--------------------------------------|--------------------------|-------------------------|
| | Before Desulphurization. | After Desulphurization. |
| As sulphide | 0·59 | 0·535 |
| As sulphate | 0·06 | 0·040 |
| Total..... | 0·65 | 0·575 |
| Per cent. of ash in the coke | 7·05 | 7·00 |

Hence, 12·50 per cent. of the sulphur existing in the state of sulphide was evolved.

Only unweighable traces of alumina in the state of a soluble salt were detected by analysis in the two cokes; but they contained 0·20 per cent. of lime, which, it was inferred, was present in the state of sulphate.

In the experiments at Cockerill's works, the coke operated upon was made from unbroken lumps of coal or from washed slack, and the duration of the coking process was in general from forty to forty-eight hours. The coke was put into the cylinder immediately after leaving the oven, in order that it might retain the whole of its heat. In the first trials the charge of coke was contained in two waggons, each holding from 700 to 800 kilogrammes; but owing to the intense heat disengaged from the incandescent mass of coke, and the consequent frequent burning of the luting (*bouillage*) of the covers of the cylinder, only one waggon holding about 800 kilogrammes of coke was put into the cylinder.² The cylinder was thus heated to a degree sufficient to cause water dropped upon it to assume the spheroidal state. The volume of air injected was estimated at 2 cubic metres per minute, and a pressure of between two and two and a half atmospheres

¹ The temperature at which these experiments were conducted is not stated: it is therefore presumed that the temperature recommended by MM. Grandidier and Rue (250° C. to 300° C.) was employed.

² It is not stated what material was used as a luting to render the covers airtight. If proper caution and foresight had been exercised in selecting a suitable material, the difficulty mentioned in the text ought not to have arisen.

was maintained in all the experiments. An hour after the blowing machine was set in operation, a slight odour of sulphurous acid began to be perceived in the escaping air, and the disengagement of this acid became more and more intense as the experiment proceeded. After the lapse of three hours the cylinder had become pretty well cooled, and the mass of coke completely black.

So far from the whole of the sulphur being removed by this process, according to the statement of MM. Grandidier and Rue, it was found that only about 7 per cent. of that which existed in the state of sulphide was evolved in these experiments. The statement also of the inventors, that the porosity of coke is increased by subjecting it to their process, was disproved.

The loss of carbon by oxidation in this process does not appear to be nearly so great as when the coke is exposed at a higher temperature to the action of atmospheric air under the ordinary pressure, as in Philippart's experiments described on p. 470: on the other hand, the combustibility of carbon will be increased in proportion to the increase in pressure of the air to which it is exposed.

IV. DESULPHURIZATION OF COKE BY CHLORIDE OF SODIUM.

The late Mr. Calvert, of Manchester, patented a method of desulphurizing coal by coking with the addition of common salt; the principle of this method he explains as follows:—"By the action of heat, bisulphide of iron is decomposed into protosulphide, which, in contact with chloride of sodium, forms, amongst other products, chloride of iron, which, in the presence of the vapour of water at a high temperature, is resolved into oxide of iron and hydrochloric acid."³ In this explanation, however, it is not stated in what form the sulphur is supposed to be separated from the sulphide of iron, nor is any experimental evidence given concerning the reaction by which such separation may be effected.

Mr. Calvert published the results of numerous experiments which would appear to lead to the conclusion that cast-iron melted in cupolas with *salted coke* contains less sulphur than when melted with ordinary coke. These results are not, in my judgment, conclusive. To determine the desulphurizing effect ascribed to salt in a satisfactory manner, a given variety of coal should be coked with and without the salting process, and the sulphur retained in the coke in each case should be exactly determined. I wrote to Mr. Calvert to ascertain whether he had made experiments of this kind, and in reply he communicated to me the following comparative results:—Coke prepared without salting from a coal occurring in North Staffordshire contained 2.56 per cent. of sulphur; whereas salted coke from the same coal contained only 0.72 per cent. But it would not be safe to rely on the

³ Comptes rendus, 1852, xxxv. 433. Date of the patent A.D. 1851, Oct. 30, No. 18,798. The specification of Mr. Calvert's patent contains a claim to de-
phosphorize coke, as well as to desulphurize it, by means of salt in the manner explained.

DESULPHURIZATION OF COKE BY CHLORIDE OF SODIUM. 475

results of this single experiment; and I am rather surprised that, as Mr. Calvert attached much importance to his process, he should not have sought to establish it on unquestionable data.

Philippart has experimented in the laboratory upon the salting process, and his conclusion is that no advantage is derived from it. Some of his results are presented in the following table:—

TABLE SHOWING THE PROPORTIONS OF SULPHUR AND ASH IN ORDINARY COKE, AND IN COKE MADE FROM COAL MIXED WITH SALT.*

| Number of the Coal. | Percentage of Sulphur in the Coal treated. | Percentage of Sulphur in the Coke produced without the addition of Salt. | Percentage of Sulphur in the Coke produced after the addition of 10 per cent. of Salt. | Percentage of Ash yielded by the Coal. | Percentage of Ash yielded by the Coke produced without the addition of Salt. | Percentage of Ash yielded by the Coke produced after the addition of 10 per cent. of Salt. |
|---------------------|--|--|--|--|--|--|
| I. | 0.50 | 0.45 | 0.475 | 5.00 | 5.55 | 5.20 |
| II. | 4.25 | 2.30 | 2.25 | 14.25 | 16.25 | 15.00 |
| III. | 0.50 | 0.465 | 0.675 | 9.50 | 11.80 | 12.85 |

CONCLUDING REMARKS ON THE DESULPHURIZATION OF COKE.

The term desulphurization has been, I think improperly, applied to processes which have for their object, not the evolution of sulphur from the protosulphide of iron in coke, but its transference from the iron to some other substance with which it remains in combination and does not in that state produce any deleterious effect, as in iron-smelting for example. Carbonate of soda, lime, carbonate of lime, and oxide of manganese are some of the substances which, with that view, it has been proposed to mix with coal preparatory to coking. The reactions which take place when protosulphide of iron is heated to redness in admixture with either of the first two substances and carbon will be found stated in my volume on Iron and Steel. Sulphide of sodium or calcium is formed in a considerable degree, but the reduction of the sulphide of iron is not complete, double sulphides of iron and sodium or calcium being produced. In the same volume it is also stated that when a highly manganiferous iron ore is smelted the slag has been found to contain much sulphur in the form of sulphide.

Laboratory experiments on the quality of coke produced by coking coal mixed with each of the substances above-named have been made by Philippart, and reported in his paper on the desulphurization of coke. His conclusions are as follow:—

1. Coke made by the carbonate of soda treatment above mentioned is not better than that made from the same coal without it.

* Revue Universelle, 1871, xxviii. 302, 303.

2. Intermixture of coal and carbonate of lime or lime tends to neutralize the injurious effects of the sulphide of iron in the coke.

3. Oxide of manganese acts like lime, but less efficaciously.

Not one of the foregoing schemes has come into use, and the increase in the cost of manufacturing coke which they necessitate will always be a serious drawback. In order that they should be effective, the mixture of the coal and material added must be intimate, and that implies reduction of the coal to a fine state of division and consequent additional expenditure. They could obviously only be applied to caking coals. If they should ever be adopted, it will be in establishments where the cleansing of such coal by washing processes has been carried out most successfully, and where the coal is previously ground pretty fine.

YIELD OF COKE.

The yield of coke will obviously vary considerably with the variety of coal used, and especially with the amount of oxygen and hydrogen which the coal contains: it will also vary with the method of coking, and with the temperature at which the process is conducted (see p. 421 *supra*). In estimating the yield by volume it must be borne in mind that some coals swell, whilst other coals contract during coking; and in estimating it by weight, the quantity of water retained by the coke, after extinction, is a point of much importance.

Numerical statements of yield will be found in the following article on the Cost of Coking and in the descriptions of particular ovens.

COST OF COOKING.

I. At the Dowlais Ironworks, Merthyr Tydvil (November 1860).⁵ The ovens are simple arched rectangular chambers, of the ordinary construction, in which air enters through the top of the door in front, and the volatile products escape into a chimney at the back provided with a damper. They are 13 feet long, 6 feet wide, and 4 feet 6 inches high from the floor to the top of the arch. The thickness of coal when charged is about 27 inches, the quantity of coke drawn is 50 cwt., and the time of coking 48 hours. The coal from which coke for the blast-furnaces is made, consists of a mixture of caking coal from the Troedyrhiw or uppermost seam, with from $\frac{1}{3}$ to $\frac{1}{2}$ of small semi-bituminous—i.e. non-caking, rich in carbon—blast-furnace coal. From 25 to 26 cwt. of coal produce 1 ton, i.e. about 78 per cent., of coke. The cost of labour for simply coking, that is, filling the oven, tending the burning, and drawing, amounts to $7\frac{1}{10}$ d. per ton. At one batch of 60 ovens a small steam-engine is employed for drawing the coke from the ovens; this saves 1d. per ton in labour, which is thus reduced to $6\frac{1}{10}$ d. per ton. There are the extraneous charges of filling the coke-waggons and horsing them to the furnaces, which raise the cost of labour on

⁵ The information was kindly supplied by Mr. Menelaus, who was then, and still is, the manager.

the coke when delivered at the furnaces to 1s. 2d. per ton. The cost, per ton of coke, of bricks and clay, for repairs, etc., is from $\frac{1}{10}$ d. to $\frac{8}{10}$ d.; and of castings, bar-iron, and stores, $1\frac{1}{2}$ d. The total cost, per ton of coke, inclusive of labour, is as follows:—

COST OF COKING AT THE DOWLAIS IRONWORKS, IN 1860, PER TON OF
COKE PRODUCED.

| | s. | d. |
|--|----|------------------|
| Labour in coking..... | 0 | 6 $\frac{7}{10}$ |
| Extraneous labour and hauling to the furnaces..... | 0 | 7 $\frac{4}{10}$ |
| Castings, bar-iron, and stores | 0 | 1 $\frac{1}{10}$ |
| Bricks and clay | 0 | 0 $\frac{6}{10}$ |
| | 1 | 4 $\frac{1}{10}$ |

The coke is not cooled by watering in the ovens, and this accounts for the small charges for bricks and repairs.

II. In Cox's ovens at the Ebbw Vale Ironworks, Monmouthshire:⁶ a description and engravings of these ovens have been given at p. 435. The cost of the ovens is from £75 to £80 each. The cost of repairs is 3d. per ton of coke. The cost of coking (November 1860) is 1s. 5d. per ton of coke, statute weight of 2240 lbs.; but this has been reduced to 1s. 1d. per ton (June 1861). The late Mr. Cox, the inventor of the ovens, used to conduct the process of coking by contract, and to find all the labour, the Ebbw Vale Company supplying bricks, clay, and iron. All the coals at Ebbw Vale are coked. The yield of coke is 70 per cent. of the weight of the coal; and when the ovens are in good order and making *best* coke, it is as much as 72 per cent. The coke is cooled by watering in the ovens. The water retained in the coke, according to Mr. Parry's determination, is under 1 per cent. The weight of a cubic foot of coke deduced from the weight of a truck filled with coke and containing 171 $\frac{1}{2}$ cubic feet was 29 lbs.; and in a similar determination with a truck containing 256 $\frac{3}{4}$ cubic feet, it was found to be 32 lbs.

III. At the Blaina and Cwm Celyn Ironworks, Monmouthshire (November 1860).⁷ At the Blaina works in outdoor coking in long piles, or, as they are termed, "pits," the cost is 7 $\frac{1}{2}$ d. per ton of *pig-iron made*. It is a practice in some works thus to contract with the coker on the iron made. For sale-cokes the cost by the same process is 6 $\frac{1}{2}$ d. per ton of coke. At the Cwm Celyn works the cost of coking in Cox's and other ovens is 6 $\frac{1}{2}$ d. per ton of coke on the ton of *pig-iron made*. The late Mr. Levick, one of the proprietors of the works, at my request, was so good as to have the following determinations made:—

| | Tons. | cwt. | qr. |
|--|-------|------|-----|
| The weight of Elled coal in two of Cox's ovens amounted to | 4 | 13 | 0 |
| The coke produced weighed | 4 | 0 | 0 |

The coal measured 8 $\frac{1}{2}$ cubic yards; and the coke, after having been broken in pieces, 10 $\frac{1}{4}$ cubic yards. In measuring, a box of 3 feet

⁶ The information was kindly supplied | by the late Mr. Levick, proprietor of the
by Mr. Adams, formerly manager. | works.

⁷ The information was kindly supplied |

square and 18 inches deep was employed; and the measurement was "strike" measure, a portion of small coal or coke being used to level the top. The coke after having been drawn was heavily watered, and was found to retain 16 per cent. of water: hence,—

| | |
|---|-----------|
| The percentage of coke produced was | 86 |
| " water to be deducted..... | 16 |
| Percentage of dry coke | <u>70</u> |

The foregoing information concerning the cost of coking in 1860, may serve as a useful guide even now: but it need hardly be observed that a liberal addition must be made to nearly every item of cost in estimating the probable expense of coking at the present time.

COMPOSITION AND CALORIFIC VALUE OF THE WASTE-GASES OF COKE-OVENS.

We are indebted to Ebelmen for analyses of the gases of coke-ovens at Seraing, in Belgium.⁸ A description of the arrangements adopted at these ovens for utilizing the waste heat and gases will be found at p. 485. Ebelmen has given the following information respecting the ovens he used in his experiments:—The floor of the oven is a rectangle terminated at each end by a trapezium. The roof is cylindrical above the rectangle, and conical above the trapeziums. There are three chimneys in a line: one in the centre of the cylindrical part of the roof, and one on each side at the junction of the cylindrical with the conical part of the roof. The area of the central chimney is double that of each of the others. The three chimneys are never in use at the same time: the two lateral chimneys are closed when the central one is open, and conversely. The central chimney conducts the gases which escape from the oven under the boiler of a steam-engine. Caking coal was coked in these ovens, which yielded 80 per cent. of coke, consisting of 78 parts of carbon and 2 of ashes, and 20 per cent. of volatile matters. Ebelmen gives no elementary analysis of this coal, but inferred its composition from that of a coal at Rochebelle, near Alais, which yielded very nearly the same percentage of coke; namely, 78 per cent., and of which the following analysis was made by Regnault:—

COMPOSITION, PER CENT., OF COAL FROM ROCHEBELLE USED FOR COKING.

| | |
|--------------------------|---------------|
| Carbon | 89·27 |
| Hydrogen..... | 4·85 |
| Oxygen and nitrogen..... | 4·47 |
| Ash | 1·41 |
| | <u>100·00</u> |

The charge for each oven is 3 cubic metres (= 2750 kilogr. or 2 tons 14 cwt. 16 lbs.) of small coal, which is spread as evenly as possible

⁸ Recueil des Travaux scientifiques, ii. 142.

over the floor, forming a stratum about 0.33 metre (= 12.99 inches) in thickness. All the chimneys are open at this time for the comfort of the workmen. When the charging is over, the lateral chimneys remain open while the central one is closed, and continue so for two or three hours; the doorways are closed, but not luted, and carbonization commences. It may be divided into three stages, as follows:—In the first stage, which lasts about three-quarters of an hour, there is only disengagement of water; in the second stage, which lasts about an hour and a half, the gases take fire and partially burn with a very smoky red flame, the lateral chimneys remain wide open, and the doorways are closed, but not luted; in the third stage, the gases burn well with a smokeless white flame. The coal appears incandescent to the depth of 8 or 10 centimetres (3 to 4 in.) from the surface; the doors are then luted, and only a small fissure is made in the clay luting at the upper part. The lateral chimneys may now be closed, and the central one entirely opened. When the flame begins to decrease, the fissure in the clay luting is gradually contracted and at last completely stopped, and when flame ceases the central chimney is closed. The period of coking, inclusive of charging and drawing, lasts from 22 to 24 hours. The average yield of coke is 160 per cent. in volume, and 67 per cent. in weight.¹ Ebelmen analysed the gases collected from these ovens at three different stages of the process, and obtained the following *volumetrical* results:—

TABLE SHOWING THE COMPOSITION, PER CENT., BY VOLUME OF THE GASES EVOLVED FROM COKE-OVENS AT SERAING DURING COKING.

| | I. | II. | III. | IV. |
|---|---------------|---------------|---------------|---------------|
| Carbonic acid | 10.18 | 9.60 | 13.06 | 10.93 |
| Carbonic oxide | 4.17 | 3.91 | 2.19 | 3.42 |
| Marsh-gas | 1.44 | 1.68 | 0.40 | 1.17 |
| Hydrogen | 6.28 | 3.67 | 1.10 | 3.68 |
| Nitrogen | 77.98 | 81.16 | 83.25 | 80.80 |
| | <u>100.00</u> | <u>100.00</u> | <u>100.00</u> | <u>100.00</u> |
| Number of volumes of oxygen combined with carbon in relation to 100 volumes of nitrogen. | 15.7 | 14.2 | 17.0 | 15.63 |

I. Gas collected, two hours after the kindling of a charge, from one of the lateral chimneys of an oven; smoke black and dense; reddish flame appearing at intervals. II. Gas collected $7\frac{1}{2}$ hours after charging; bright, but still somewhat reddish, flame, without smoke. III. Gas collected after 14 hours' coking; flame clear, but little in volume;

¹ It has been stated above that the coal used yielded 80 per cent. of coke. Hence there is an apparent discrepancy of considerable importance between the two statements in the text. The probable explanation is that the yield of 80 per cent. was obtained by coking in some other manner or form of oven. The bad-

ness of the yield in the Seraing ovens is confirmed by the statement on p. 480 of the quantity of each element removed by combustion or volatilization during the process of coking, from which it appears that upwards of 70 per cent. of the matter so removed consisted of carbon.

carbonization being apparently near completion. IV. The mean of I, II, and III.

The relation in *weight* between the elements contained in the mean of the gases (IV. in the preceding table), is as follows: ²—

| | | | |
|----------------|--------------------------|--------|---------|
| Carbon | { In carbonic acid | 1.408 | } 2.004 |
| | { In carbonic oxide..... | 0.443 | |
| | { In marsh-gas | 0.153 | |
| Oxygen | { In carbonic acid | 3.758 | } 4.348 |
| | { In carbonic oxide..... | 0.590 | |
| Hydrogen | { In a free state | 0.079 | } 0.130 |
| | { In marsh-gas | 0.051 | |
| Nitrogen | | 24.353 | |
| | | 80.835 | |

Oxygen which has disappeared, as deduced from the ratio existing between nitrogen and oxygen in atmospheric air } 2.925 ³

The percentage of coke obtained in these ovens was 67, so that 33 per cent. of the coal had been removed either by volatilization or combustion. Now, assuming that the composition of the coal used was identical with that of the Rochebelle coal previously given, and supposing that the 67 per cent. of coke consisted only of 65.59 parts of carbon and 1.41 of ashes, it follows that the 33 per cent. of matter removed during coking contained the following elements:—

| | |
|--------------------------|-------|
| Carbon | 23.68 |
| Hydrogen | 4.85 |
| Oxygen and nitrogen..... | 4.47 |
| | 33.00 |

Thus, the relation in *weight* between the carbon and hydrogen is as 1:0.205; but the relation in weight between the carbon and hydrogen deduced from the mean composition of the gases above stated is as 1:0.065. Hence, Ebelmen draws the conclusion that more than two-thirds of the hydrogen contained in the coal are burned during the process of coking, and thus, being converted into water, this part of the hydrogen does not appear in his analyses. He remarks, however, that in this computation no account is taken of the amount of tar and other condensable matters evolved during the process; but he considers that, in consequence of the very high temperature of the oven during nearly the whole period of coking, the proportion of condensable products is of little account, and that it is only at the

² Data from which these calculations have been made at 760 mm. (= 30 in.) pressure, and 15.5° C. (60° F.):—

| | Grains. |
|--|---------|
| 100 cubic inches of carbonic acid weigh..... | 47.26 |
| „ carbonic oxide „ | 30.21 |
| „ oxygen „ | 34.29 |
| „ hydrogen „ | 2.14 |
| „ marsh-gas „ | 17.41 |
| „ nitrogen „ | 30.14 |

³ 24.353 of nitrogen are associated with 7.273 of oxygen in atmospheric air: hence, 7.273 - 4.348 = 2.925.

beginning of the operation that they are disengaged in appreciable quantity. It must be borne in mind that the data from which Ebelmen draws his conclusions involve an assumption as to the composition of the coal of which no analysis was made.

The *volume* of oxygen, combined with carbon, in the mean of the gases (IV. in the table, p. 479), is to that of the nitrogen as 15.63:100; whereas the relation in volume between the oxygen and nitrogen which entered the oven in the state of atmospheric air is as 26.26:100. The difference, 10.63, represents the volume of oxygen which has served to burn the hydrogen. Hence two-fifths (by *weight* as well as by *volume*) of the oxygen of the air introduced into the coke-oven have been converted into water. In this calculation Ebelmen remarks that the small amount of oxygen contained in the coal has been neglected, but that the correction required to be made in consequence will not sensibly affect the conclusions enunciated.

The quantity of atmospheric air which the process of coking will require may also be deduced from the composition of the gases. The relation in *weight* between the nitrogen and carbon in the mean of the gases is as 12.2:1. Atmospheric air contains 77 per cent. of nitrogen by weight; consequently, for 1 part by weight of carbon in the gases, 15.8 of air will enter the oven. Now, it has previously been stated that the quantity of carbon carried off in the gases is 23.68 per cent. of the weight of the coal; the weight of air, therefore, introduced during the process of coking is to that of the coal as 3.74:1. Hence, in coking 2 tons 14 cwt. 16 lbs. (= 2750 kilogr.) of coal, not less than 10 tons 2 cwt. 55 lbs. of air will be required, or in volume 296188 cubic feet (100 cubic inches of air weigh 31.0117 grains, or 1 lb. of air = 13.06 cubic feet). Supposing the duration of the coking process to be 24 hours, 12341 cubic feet of air will enter the oven per hour, very nearly 205.7 cubic feet per minute, and 3.43 cubic feet per second. Ebelmen estimated that this amounted to about two-thirds of the air blown into a charcoal iron-smelting furnace yielding 2 tons of pig-iron in the 24 hours.

From the data which Ebelmen obtained in his investigation concerning the composition of the gases of the coke-ovens at Seraing may be approximately calculated the amount of heat produced during the process of coking, as well as the amount which may be further developed by the complete combustion of the carbonic oxide, hydrogen, and marsh-gas existing in those gases. Ebelmen made such a calculation, and came to the conclusion that two-thirds of the heat capable of being evolved by the complete oxidation of the volatile products were rendered sensible in the ovens, and only one-third remained to be generated by the subsequent oxidation of the combustible constituents of the gases which escaped from the ovens.

Suppose that the coal employed yielded 67 per cent. of coke, and 33 per cent. of volatile products, consisting of 4.85 of hydrogen, 23.68 of carbon, 2.97 of oxygen, and 1.50 of nitrogen; and grant that only the amount of hydrogen in excess of what is required to form water with the oxygen in the coal is available as a source of heat, namely 4.479.

Then, for 1 part by weight of coal, 0.04479 of hydrogen and 0.2368 of carbon will be evolved and partially burnt during the process of coking; and the number of units of heat which will be produced by the conversion of the hydrogen into water and the carbon into carbonic acid will be respectively $0.04479 \times 34000^4 = 1522.860$, and $0.2368 \times 8080^5 = 1913.344$. But as the water formed from the hydrogen will pass off as steam at the temperature at least of 100°C. , it is necessary to deduct the latent heat of that steam; for it will be remembered that in the determination of the calorific power of hydrogen in the calorimeter, the vapour of water produced is condensed, and its latent heat rendered sensible. Not only must the latent heat of the steam, resulting from the combustion of the disposable hydrogen, be deducted, but also that of the non-disposable hydrogen, which is supposed to exist as water in the coal. Hence the total amount of latent heat to be deducted is $0.0485 \times 9 \times 537 = 234.400$. The real number of available units of heat from the hydrogen will, consequently, be $1522.860 - 234.400 = 1288.460$; and the sum of the units of heat capable of being produced from the carbon and hydrogen, which are evolved from 1 part by weight of coal, but only partially burnt during the process of coking, will be $1913.344 + 1288.460 = 3201.804$.

The number of units of heat resulting from the combustion effected within the oven during the coking process is easily found. The total quantity of carbon in the gases produced from 1 part by weight of coal is 0.2368, since 100 parts of coal yielded 33 per cent. of such products, of which 23.68 consisted of carbon. Now, in the mean of the gases of the coke-ovens at Seraing (IV. in the table, p. 479), which contained 2.004 parts of carbon by *weight*, 1.408 were present in carbonic acid, 0.443 in carbonic oxide, and 0.153 in marsh-gas. Hence, of the total weight of carbon, 0.2368, in the gases produced during the coking of 1 part by weight of coal, 0.1664 existed in carbonic acid, 0.0523 in carbonic oxide, and 0.0181 in marsh-gas. The number of units of heat, therefore, resulting from the combustion of carbon in the oven is $(0.1664 \times 8080) + (0.0523 \times 2473^6) = 1473.850$. The weight of hydrogen burnt in the oven is $0.04479 - 0.01536 = 0.02943$ per unit weight of coal; and the number of units of heat which will result from its combustion, making the deduction required for the latent heat of the steam thereby produced as well as of the steam which is represented by the non-disposable hydrogen in the coal, is $(0.02943 \times 34000) - [(0.02943 + 0.00371) \times 9 \times 537] = 840.455$. The total number of units of heat resulting from the combustion of carbon and hydrogen in the oven is therefore $1473.850 + 840.455 = 2314.305$.

The number of units of heat which will be evolved by the perfect

⁴ The calorific power of hydrogen. I have retained the numbers which Ebelmen made use of. The calorific power of hydrogen, as determined by Favre and Silbermann, is 34,462. Compare the articles on Calorific Power and Calorific

Intensity, pp. 159-173 *supra*.

⁵ The calorific power of carbon.

⁶ The calorific power of carbon when the product of its combustion is carbonic oxide; see p. 163.

combustion of the carbonic oxide, hydrogen, and marsh-gas in the gases escaping from the ovens, may also be found in a similar manner. The carbon and hydrogen in marsh-gas may be regarded as in a free state, since the calorific power of this gas is nearly the mean of the calorific powers of its constituents. Hence, in the gases produced during the coking of 1 part by weight of coal, $0.04479 - 0.02943 = 0.01536$ of hydrogen will be present in a practically free state, and the number of units of heat which will result from the combustion of this hydrogen, making the deduction required for the latent heat of the steam produced, is $(0.01536 \times 34000) - (0.01536 \times 9 \times 537) = 448.005$. The number of units of heat which will be developed by the combustion of the carbon in carbonic oxide is $0.0523 \times 5607^7 = 293.246$; and by the combustion of the carbon in marsh-gas, $0.0181 \times 8080 = 146.248$. Therefore the total number of units of heat remaining to be produced by the complete combustion of the gases which escape from the oven is $448.005 + 293.246 + 146.248 = 887.499$.

From the preceding data it appears that the total maximum number of units of heat, capable of being evolved by the perfect combustion of the carbon and hydrogen, separated from 1 part by weight of coal during the process of coking, is 3201.804; of which number 2314.305 units are produced during the process of coking, and 887.499 remain to be produced from the gases evolved. Hence the ratio between the number of units of heat produced, and of those which remain to be produced, somewhat exceeds 2 : 1. And it follows that the maximum number of units of heat capable of being developed during the coking of 2750 kilogr. of this coal is 8804961000, of which 2440622000 remain to be produced by the combustion of the gases escaping from the oven. A tabular statement of the foregoing calculations will be found on p. 484.

The preceding approximate calculations must be correct, if the data upon which they are founded be true. But let us now enquire whether we have reason to doubt the truth of these data. In the mean of the gases (IV. in the table, p. 479), 24.353 parts by weight of nitrogen were associated with 4.348 of oxygen, which existed in combination with carbon. In atmospheric air the same weight of nitrogen is associated with 7.273 of oxygen; and as the nitrogen present in the gases was *practically* all derived from atmospheric air, it follows that $7.273 - 4.348 = 2.925$ parts by weight of oxygen have disappeared in consequence of its combining with hydrogen during the process of coking. But the relation in weight between the oxygen which has disappeared and the carbon in the mean of the gases is as 2.925 : 2.004 (see p. 480). Hence the weight of the oxygen which has disappeared in the coking of 1 part by weight of coal is $0.2368 \times (2.925 \div 2.004) = 0.3456$. But 0.3456 of oxygen would require 0.0432 of hydrogen to combine with it during the process of coking; and if we add to this 0.01536, the weight of hydrogen evolved partly

⁷ The calorific value of that weight of carbonic oxide which contains one unit weight of carbon; see p. 163.

TABULAR STATEMENT OF THE PRECEDING CALCULATIONS OF THE AMOUNT OF SENSIBLE HEAT PRODUCED, AND OF COMBUSTIBLE GASES EVOLVED, DURING THE PROCESS OF COKING IN OVENS AT SERAING.

| Weight of each Element evolved during Coking per unit weight of Coal. | Supporter of Combustion. | Product of Combustion. | Units of Heat evolved. | Latent Heat to be deducted. | Available Units of Heat. | |
|---|---|-------------------------------|------------------------|-----------------------------|--------------------------|---|
| O 0.2368 | O of air | carbonic acid | 1913.344 | .. | 1913.344 | Units of heat available by the perfect combustion of the carbon and hydrogen evolved from one part by weight of coal during coking..... = 8201.804 |
| H 0.0485 = {0.04479... 0.00371...} | O of air | water | 1522.860 | 234.400 | 1288.460 | |
| O 0.0297 | virtually exist in combination in the coal. | | nil. | .. | .. | |
| N 0.0150 | nil | nil | .. | .. | .. | |
| Weight of Carbon and Hydrogen burnt in the Oven. | Supporter of Combustion. | Product of Combustion. | Units of Heat evolved. | Latent Heat to be deducted. | Available Units of Heat. | |
| O 0.2187 | O of air | carbonic acid | 1344.512 | .. | 1344.512 | Units of heat given out by the combustion of carbon and hydrogen in the oven = 2314.305 |
| H 0.02943 | O of air | carbonic oxide | 129.338 | .. | 129.338 | |
| | O of air | water | 1000.620 | 160.165* | 840.455 | |
| Weight of Carbon and Hydrogen to be burnt after leaving the Oven. | On leaving the Oven, exists as | Product of Combustion in air. | Units of Heat evolved. | Latent Heat to be deducted. | Available Units of Heat. | |
| O 0.0704 | carbonic oxide | carbonic acid | 293.246 | .. | 293.246 | Units of heat obtainable by the perfect combustion of the carbonic oxide, marsh-gas, and free hydrogen which escape from the oven..... = 887.499 |
| | marsh-gas .. | (ditto) | 146.248 | .. | 146.248 | |
| H 0.01536 | free | (water) | 522.240 | 71.235 | 448.005 | |
| Total, as above..... | | | | | | 8201.804 |

* Includes the latent heat of the hydrogen and oxygen, assumed to exist in combination, as water, in the coal.

free and partly in combination with carbon as marsh-gas, we obtain 0.05856 as the total weight of disposable hydrogen per unit weight of coal, which is $0.05856 - 0.04479 = 0.01377$ in excess of the true weight. It may, therefore, be inferred that the data of Ebelmen cannot all be correct. The composition of the coal, and the weight and elementary composition of samples of the gases produced during the process of coking, may be exactly determined; but it must, obviously, be very difficult to arrive at the correct average composition of the gases and volatile products evolved during the whole process of coking. The three specimens of gas which Ebelmen collected at intervals of 2 hours, $7\frac{1}{2}$ hours, and 14 hours after the commencement of the process, are assuredly quite insufficient for the purpose. Thick yellow smoke is copiously evolved at an early stage of the process; but the matter which produces this smoke, and which cannot be inconsiderable in amount, is not represented in the mean composition of the gases collected. It seems, therefore, most probable that the opposite conclusions concerning the amount of hydrogen consumed during the process of coking are due to an error in the average composition of the gases.

Nevertheless it is certain that not only is a large amount of heat developed in the process of coking, but also that a considerable additional amount may be obtained by the combustion of the carbonic oxide, hydrogen, and marsh-gas existing in the gases which escape from the ovens. But whether these combustible gases, which are mixed with so large a proportion of carbonic acid and nitrogen, can be *perfectly* burned by atmospheric air seems to be more than doubtful.

Ebelmen draws the practical and obvious conclusion that, as a very large proportion of the heat available from coke-ovens is *sensible* heat, it is desirable that the distance between the ovens and the place of the application of the waste-gases escaping from them should be as short as possible.

Mr. Menelaus has recently informed me (June 1873) that the utilization of the waste heat of coke-ovens has been subjected to lengthened trial in the North of England, and adopted with complete success; but it has not as yet been so largely introduced in South Wales.

APPLICATION OF THE WASTE HEAT AND GASES OF COKE-OVENS TO RAISING STEAM AT SERAING.

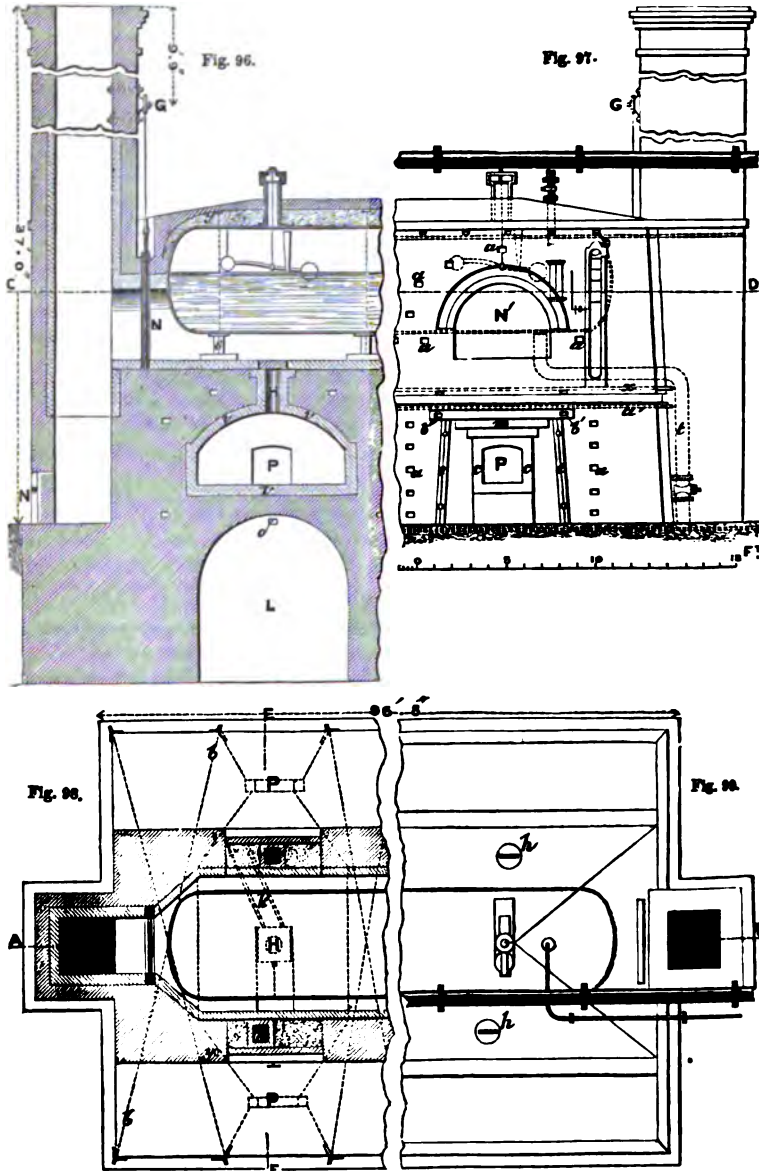
A successful application of the sensible heat and waste-gases, produced in coking, to the heating of steam boilers has long been in operation at Seraing; and of the arrangements adopted for the purpose I introduce the following description by Valérius.⁸

The general arrangement of the ovens is shown in the accompanying woodcuts, figs. 96-100.

The ovens are built of double courses of brickwork, one of fire-

⁸ *Traité théorique et pratique de la Fabrication de la Fonte, etc.*, pp. 256 *et seq.*

brick within, *ee*, fig. 96, and the other of common brick; the floor of fire-bricks is laid flat; there is a chimney, *H*, in the middle of the



Mode of applying the waste heat and gases of coke-ovens at Seraing to the raising of steam.

Fig. 96. Vertical section on the line *a a*, figs. 98 and 99.

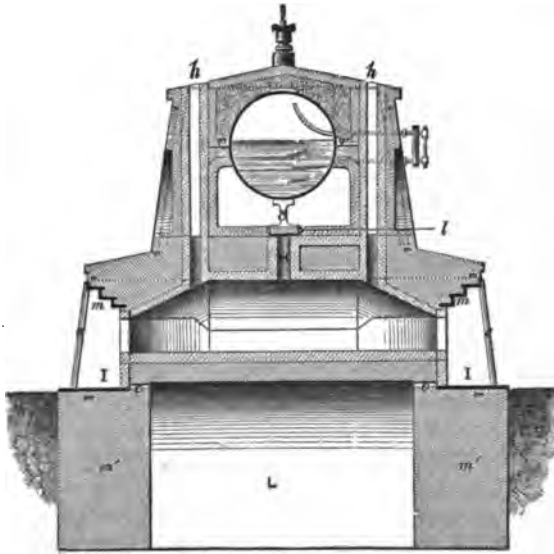
Fig. 97. Elevation.

Fig. 98. Horizontal section on the line *c d*, figs. 96 and 97.

Fig. 99. Plan of the top of the oven.

oven; and smaller chimneys, *h h*, at the commencement of the conical part of the roof; the size of the transverse sectional area of the

chimney, *H*, exerts a great influence upon the process of carbonization; it is equal to, or somewhat greater than, the sum of the transverse sectional areas of the two chimneys, *h h*; *PP* are doors for charging and drawing, and *II*, plates of cast-iron on the level of the ground under each door, in order to receive the coal to be charged, and the coke at the time of drawing; *cc* are cast-iron door-frames let into the brickwork; *mm* are cast-iron bearers to support the brickwork above the door; there is an arched vault, *L*, upon which the floor of the oven rests; the vault is intended to protect the oven from the moisture of the ground; *m' m'* are walls which close the ends of the vault; *oo* are holes above the ground by which air may circulate through the vault; *aa*, fig. 97, are little channels left in the brickwork between two contiguous ovens, and at the ends of the pile of building



Mode of applying the waste heat and gases of coke-ovens at Seraing to the raising of steam.
Fig. 100. Vertical section on the line *x x*, fig. 98.

on each side of the main chimneys; they ramify through every part of the brickwork, and may act as vents to the long flue subsequently mentioned, with which some of them are in communication. As the ovens have to support considerable weight, as well as the strain caused by changes of temperature, they ought to be firmly braced, in order to prevent the brickwork from splitting. The mode of bracing is shown in figs. 97 and 98; in fig. 98, the dotted lines, *b b*, are bars of $\frac{3}{4}$ -inch iron, which extend diagonally through the brickwork, and tie firmly together the cast-iron standards, *cc*, fig. 97, and bearers, *m*, above; these standards are made angular, so as to fit on and protect the free edges of the piers at each entrance of the oven; *b' b'*, fig. 97, are the ends of tie-rods of $\frac{3}{4}$ -inch iron, which traverse the piers parallel to the long axis of the oven, and fix by means of screws and nuts the upper bearers above the two doorways of

the oven; there are flat tie-rods of iron, *a'*, fig. 97, three inches broad and half an inch thick, almost wholly enclosed in the brickwork, and intended to hold together the whole pile of building from end to end; there are two such bars on each side, one a little below the level of the ground, and the other a little below the coping of the ovens. The door-frame is of cast-iron, and the door, which moves on hinges, consists of a frame of cast-iron filled with fire-bricks; in the upper part of the door is a hole $\frac{3}{4}$ -inch in diameter, through which air enters, and the interior of the oven may be inspected. Eight of these ovens are built in a row under one boiler, which produces steam sufficient for an engine of 80 horse-power. At each end is a main chimney, and from one main chimney to the other extends a long flue, into which open all the central chimneys of the ovens. The transverse sectional area of each main chimney is equal to the sum of the areas of all the central chimneys through which the gases pass under the boiler. The main chimneys are used alternately, so that when one is in communication with the long flue, communication between the other and this flue is cut off by means of the damper, *GN*; there are channels of cast-iron, shown by dotted lines at *k*, fig. 98, which lead from the external air and terminate upon the floor of the long flue at the openings through which the gases enter from the ovens underneath; these channels convey air necessary for the combustion of the gases which escape from the ovens; there are sliding dampers of fire-brick, *l*, fig. 100, which may be moved by iron rods so as to close, when necessary, the openings which admit the gases to the long flue.

When the central chimneys of the ovens, *H*, are closed by these sliding dampers, as is supposed to be the case in the engravings, carbonization proceeds by means of the lateral chimneys, *h h*, which are carried up higher than is required in ovens unconnected with a boiler. That part of these chimneys which is contained within the roof of the oven is cylindrical, while that which rises above the roof is rectangular. In order that the sliding dampers may be worked, it is necessary that the lateral chimneys should not be exactly opposite each other (see fig. 98). As these chimneys are not in operation during the process of coking, they are closed at the top by plates of cast-iron, or bricks, around which coke-dust is placed. Above and corresponding to each door of the oven is an independent arched niche, *n'*. On the inner side of the brick wall included within this niche the brickwork is replaced by coke-dust (see fig. 98), through which openings can easily be made in order to examine and repair the boiler. In ovens since constructed coke-dust is not used, and the brickwork within the niche is made solid, with the exception of a doorway on one side of each lateral chimney large enough for a man to pass through. The door is formed of a frame of cast-iron filled with fire-bricks, and fits in like the lid of a tobacco-box, the sides being luted with clay. *n''*, fig. 96, is a niche through which a workman may enter each of the main chimneys. There are also niches in the sides of each main chimney, through which men

may get access to the bottom of the boiler. The brickwork of the long flue is firmly braced together longitudinally by flat iron bars, 3 inches wide and $\frac{1}{2}$ an inch thick, and transversely and vertically by similar bars, *y*, figs. 96 and 98. The boiler rests upon cast-iron props, *s*, and is also supported laterally by sixteen pieces of strong iron plate, *r r*, fig. 100, each 10 inches broad. The discharging pipe, *t*, fig. 97, is protected from heat by an outer case of fire-bricks. The upper part of the boiler is surrounded with coke-dust, which is covered in with brickwork, as shown in fig. 100. Other details, not lettered in the woodcuts—such as the water-gauge, fig. 100—will, it is hoped, be understood by any person conversant with steam-boilers.

Two rows, of eight ovens each, are built together, a space of six metres (about 20 feet) being left between the rows for convenience of passage. A single row of these ovens will raise steam sufficient for an engine, to supply blast to a furnace of large dimensions; in which coke is used as the fuel.

With a single boiler, 15 feet long and $4\frac{1}{2}$ feet in diameter, fixed over a coke-oven in nearly the same manner as shown in fig. 100, it was ascertained that 146 litres (about 32 gallons) of water could be evaporated per hour, under a mean pressure of 2.76 atmospheres, which is equivalent to an average power of 12.41 horses.

As the gases evolved at the commencement of the process of coking contain but little combustible matter and much vapour of water, they are allowed to escape by the lateral chimneys; and the central chimneys are only opened two or three hours after charging. The two main chimneys draw alternately during twelve hours; and the coking is so managed that every three hours one of the eight ovens is emptied.

The order in which the eight ovens, forming a row, are drawn is as follows; the numbers represent hours of the day (of 24 hours):—

1. 10. 7. 4. 23. 12. 18. 19.

Three advantages are thus obtained:—as the boiler throughout its entire length receives equal amounts of heat, the wear is uniform;—the combustion of the gases is secured, as the gases of the ovens in full activity pass over the openings (into the long flue) of the central chimneys of those less advanced;—the intermitting action, which is due to the irregularity in the progress of each oven taken separately, disappears, because the gases of the ovens in different stages of advancement become mixed, so as to produce a uniform effect. This last object, it is stated, is attained to perfection, as the index of the steam pressure-gauge remains stationary to a degree which it would be difficult to obtain by ordinary methods of heating.

When three rows of ovens, containing eight each, are employed, the numbers annexed indicate the order in which the charging and drawing take place, the twenty-four hours of the day being represented by the numbers from 1 to 24 consecutively:—

| First Row. | Second Row. | Third Row. |
|------------------------------|------------------------------|------------------------------|
| 4. 1. 7. 23. 10. 19. 13. 16. | 5. 2. 8. 22. 11. 20. 14. 17. | 6. 3. 9. 24. 12. 21. 15. 18. |

Valérius states that the following practical results are obtained by the utilization of the gases and waste heat of three rows of ovens, containing eight each. Over each row a boiler is fixed in the manner described. The combustion of the gases from thirteen ovens takes place at the same time, while the remaining ovens only contribute to the result by yielding sensible heat. Sufficient steam is raised for a condensing blowing-engine, which works expansively at a moderate pressure,⁹ and supplies blast to two large furnaces, in which coke is the fuel used, and also for a small steam-engine of 10 horse-power, which raises the charges up an inclined plane to the tunnel-heads of these furnaces. The diameter of the blowing-cylinder is $7\frac{1}{2}$ feet, the length of the stroke 8 feet, the number of revolutions per minute is 10, and the pressure of the blast is $3\frac{3}{4}$ lbs. on the square inch; which data, according to calculation, are equivalent to a power of 117 horses. The saving of fuel thus effected is estimated at 9360 kilogrammes, or, in round numbers, between 9 and 10 tons of coal daily.

ECONOMIC PRODUCTS GENERATED DURING COKING.

Long anterior to Murdoch's great invention of lighting by coal-gas, experiments had been made by various chemists on the nature of the products of the destructive distillation of coal. Early in the last century Hales communicated to the Royal Society the fact that half a cubic inch or 158 grains of Newcastle coal yielded in distillation 180 cubic inches of air.¹ Neumann states that "48 ounces of pit-coal distilled in a glass retort, with a fire gradually increased, yielded 2 ounces 7 drachms of phlegm, 2 ounces and 1 drachm of a thin fluid oil, and 1 ounce of a thick, tenacious, ponderous, pitchy oil, which stuck in the neck of the retort; the residuum weighed 42 ounces 7 drachms. The distilled liquors gave marks rather of an urinous and ammoniacal character, changing syrup of violets greenish, and emitting an urinous odour on the admixture of fixed alkaline salts or quicklime. The oil arose in yellow fumes, and smelled considerably sulphureous; it somewhat stained polished silver, but the stains were easily rubbed off. That which distilled at first was light, and swam on water; the succeeding parcels proved more and more gross and ponderous, and at last sunk."²

Genssane, in 1770, published a detailed and interesting account of the mode in which pit-coal was distilled at ironworks at Sulzbach. His description was founded on personal observation. The distillatory apparatus consisted of a chamber or large muffle of refractory clay, heated by a fire-place on each side. There were two openings in

⁹ "A moyenne pression." In France and Belgium steam under a pressure of from 2 to 4 atmospheres is said to be "à moyenne pression," and beyond the latter "à haute pression," or at high pressure. See Chaudel's *Formules, Tables, etc.*, 6th ed. 1864, p. 569.

¹ *Statistical Essays*, 3rd ed. 1798, i. 182.

² *The Chemical Works of Caspar Neumann, M.D.*, abridged and methodized by William Lewis, M.B., London, 1759, p. 245.

front provided with doors, an upper one through which the coal was charged, and a lower one through which the coke was withdrawn. The sides of the chamber were vertical, and the roof was arched. The bed was flat, and sloped downwards towards the back, in the bottom of which was a pipe communicating with a receiver on the outside. In this pipe was fixed another vertical pipe for the exit of the uncondensable products. There were not less than nine of these furnaces built together in a row, and at least three were in operation, while three others were cooling. When the coal was half-coked in the first three, three others were lighted, and so on in succession. As the coking generally lasted three days, the coke was withdrawn daily from three furnaces, and three others were charged. The coal lost in coking an eighth of its weight.

The charge for each furnace was about a ton of raw coal, and somewhat less than half this weight of coal was required to distil a charge. The coke was used to smelt iron. Genssane makes the following remarks:—"Coal thus cooked (*cuit*) exhales not the slightest odour in burning; and it has the advantage of lasting twice as long in the fire as wood-charcoal, instead of which it may be used for all purposes without fear of the least inconvenience. Let us reflect now on the importance of this discovery, especially in France, where wood and charcoal have become so scarce. This is not all: the oils and bitumens obtained in this operation almost pay the expenses of it. These two matters are thus turned to account. They collect together in the great receiver; the mixture is poured into a large tub, and stirred during a long time with wooden instruments worked by hand; by this manipulation the oil collects on the top, and is taken off with iron spoons, while the bitumen falls to the bottom of the tub;³ this is sometimes sufficiently pure to be at once sent into the market; but more frequently it is surcharged with water; it is then boiled in a copper until the water is evaporated, and it deposits a pulpy matter, which is thrown away. After this the pure bitumen becomes very greasy and liquid, and is in no respect inferior to the best grease for carriages. There is no difference between this oil of coal and that distilled from petroleum, except that the latter is much more inflammable and suddenly catches fire; and it may be usefully employed in lamps by people in the country. No other light is used in the mines of Sulzbach; but it smokes much, and exhales a tolerably strong smell of bitumen."⁴

The manufacture of oil for lamps and for the purpose of lubrication, by the distillation, at a low temperature, of cannel coal and other bituminous matters, is carried on largely in this country, and is reported to have formerly yielded a princely income to the firm of Young and Company. The oil thus produced contains paraffin,

³ According to Mansfield the specific gravity of coal-tar varies from about 1.120 to 1.150; the lightest samples containing the largest proportion of fluid oils. *Quarterly Journ. of the Chemical Society*

of London, 1849, i. 249.

⁴ *Traité de la Fonte des Mines par le feu du charbon de terre, etc.*; par M. de Genssane; Paris, 1770, i. 265 *et seq.*

and is accordingly designated "paraffin oil" by Mr. Young, who obtained a patent for his invention in 1850.* Although the oils used at Sulzbach probably differed somewhat from paraffin oil, yet it is not a little singular that products obtained so long ago from the distillation of coal should have been employed as agents of illumination and lubrication, just as products also derived from the distillation of coal are now applied to the same purposes.

The history of the process of coking at the ironworks at Sulzbach is interesting in another point of view, as showing how completely a great practical discovery may obtrude itself, as it were, upon the attention of men, and yet be unperceived. The chamber in which the coal was distilled was essentially a gas-retort; and the gas which issued in a continuous current from the vertical pipe at the back, must often have taken fire and produced a luminous flame; but the idea of applying that gas to the purpose of lighting seems never to have occurred to those who observed it. Large gasworks were daily in active operation at Sulzbach, and yet the merit of the invention of lighting by coal-gas was reserved for Mr. Murdoch in 1792, or more than twenty years afterwards.

In 1781 the Earl of Dundonald obtained a patent "for the extracting of tar, pitch, essential oils, volatile alkalies, mineral acids, and salts, and the making of cinders [coke] from pit-coal," by the heat of combustion developed *within* the distillatory vessel, and not on the *outside*, as, he asserts, had always previously been the practice. A regulated supply of external air was admitted into the interior of the "vessel or building" containing the coals to be distilled, "by which means the said coals after being kindled are enabled, by their own heat and without the assistance of any other fire, to throw off in distillation," etc. It was this particular mode of conducting the process which he claims as his invention, and if the claim were correct, to the Earl of Dundonald we should be indebted for the principle of the present system of coking in ovens; but it is evident from Horne's description, published in 1773, and previously inserted at p. 416, that coking was then conducted on exactly the same principle. The specification of this patent contains the following interesting passage, from which we may infer that the Earl knew that several matters were produced by the distillation of coal which possessed different degrees of condensability:—

"Exclusive of the above invention, for which only the patent has been obtained, I promote the condensation of the less coercible part of the vapour that comes off in distillation by commixing it with the steam of boiling water, and complete the condensation by the means of cold water. . . . I also cause the vapour to pass through more condensing vessels than one, to separate by that means the different oils and substances according to the different degrees of cold and moisture requisite to condense."†

In 1852 a patent was granted to Mr. W. E. Newton for "the adap-

* Specification, A.D. 1850, No. 13,292.

† Specification, A.D. 1781, No. 1291.

tation to ordinary coke-ovens of an apparatus whereby the gaseous products evolved during the combustion of coal therein may, without interfering with the ordinary process of coking, be drawn off and conveyed away to a receptacle or chamber where they may be separated from each other, and combined with other chemical agents to form valuable products, or used for some other useful purpose."⁷ Ammoniacal compounds are specially mentioned amongst the condensable products; and the residual combustible gases are conducted under steam-boilers or any other apparatus, and there burned by the admission of atmospheric air.

In 1859 the late Mr. Edward Jones, of the Russell's Hall Iron-works, near Dudley, obtained a patent for collecting and condensing mainly or wholly the tar or other condensable volatile products given off during the process of coking in open fires or heaps.⁸ I visited these works in 1860, and saw the process of condensation in operation. The fires were constructed in the usual manner with a central chimney, as described at p. 423. The bottom of the chimney was connected with an underground flue, which communicated with an old steam-boiler containing coke, and having a tap at the bottom; and the boiler, in its turn, communicated with a chimney. A series of coke-fires were put in connection with the underground flue. Before or soon after igniting the coke heap, the top of the central chimney is closed by a damper. The volatile products then pass downwards through the underground flue, and such as are condensable accumulate in the boiler, from which they are drawn off by the tap at the bottom. A considerable quantity of tar and other matters was thus obtained. I was informed that in regard to the yield and quality of coke, Mr. Jones's process was not inferior to the ordinary method of coking in circular piles.

PERNOLET'S METHOD OF COKING IN OVENS, WITH A VIEW TO THE COLLECTION OF CERTAIN PRODUCTS OF THE DISTILLATION OF COAL.⁹

A paper by Pernolet on this subject was read at the Institution of Civil Engineers, London, May 10, 1864, in which paper the chief merit of his invention is stated to consist in "utilizing the products of the distillation of coal, so as to reduce the price of coke." He asserted that he had succeeded in producing coke having "all the solidity, density, and lustre that distinguished good coke made in the ordinary way," and in turning "every product of the distillation of coal" to account. The process of coking is to be conducted "very slowly," atmospheric air is to be prevented from coming into contact with the coal, and the volatile products are passed into an apparatus suitable for condensing tarry vapour, etc., the uncondensable or permanently gaseous part of those products being either used for

⁷ Specification, A.D. 1852, No. 13,974.

⁸ Specification, A.D. 1859, No. 2158.

⁹ Two patents were granted in the name of Brooman to Pernolet, of Paris,

one dated June 14, 1862, No. 1774, and the other August 7, 1863, No. 1954. See Abridgments of Specifications relating to the preparation and combustion of fuel.

illumination after having been duly purified, or as fuel for effecting the carbonization of the coal. The floor of the oven is heated either wholly by coal or refuse coke (*i.e.* imperfectly coked coal) burnt in a fire-place underneath, or partly by coal and partly by the gas evolved during coking, and conducted through a cast-iron pipe into the fire-place, which communicates with a chimney 50 feet high. For a detailed description of Pernolet's invention, the reader is referred to sources of information stated in the foot-notes (pp. 493 and 495).

From what precedes, it will be seen that Pernolet's oven is, in fact, a gas-retort heated, as usual, by external firing. The following statement of the economic results of this method of coking is given in the abridgment of Pernolet's paper published by the Institution of Civil Engineers:—"In the great coke-works at St. Etienne, the yield [of coke] had been advanced from 58·8 to 69·3 per cent. Generally speaking, with rich, or partially rich coals, the increase in the yield of coke was from 10 to 15 per cent. As to the tar, the proportion collected depended on the nature of the coal, and on the care taken both in the distillation of the coal and in the condensation of its volatile products. It had averaged 2·53 per cent. at the Forges d'Alais, 3 per cent. at Elonges, 3·25 per cent. at St. Etienne, and had reached as high as 5 per cent. from the ovens of the Paris Gas Light Company, where only very bituminous coals were employed; but it was thought there might be reckoned 3 per cent. of tar from the bulk of the coal distilled. The proportion of ammoniacal liquors depended also on the quantity of moisture contained in the coal; but it might be stated at a weight of not less than 10 lbs. of sulphate of ammonia, and sometimes it was as much as 13 lbs. per ton of coal distilled. At the ovens of the Paris Gas Light Company, from 11,000 to 11,500 cubic feet of purified gas were generally obtained from a ton of coal, which yielded from 69 to 70 per cent. of coke, fit for delivery to the railway companies." It was further asserted that Pernolet's method had been tested by many years' experience, both in Belgium and France, where it was "actively and profitably pursued at ten different establishments, with more than four hundred ovens, of the largest dimensions, capable of receiving from 5 to 7 tons of coal at each charge." The time needed for coking varied with the nature of the coal, the density desired for the coke, and with the arrangement of the oven. At St. Etienne more than 72 hours were required for coking rich (*i.e.* highly bituminous) coals, while at Torteron only 24 hours were required for coking the "rather poor but flaring coals of Commentry."

It was stated that the cost of converting each of the ordinary ovens at St. Etienne into the Pernolet oven was about £20, and that the value of the additional yield from each oven ought to be about £60 per annum, so that the outlay should be repaid by four months' work.

The Pernolet method of coking has been tried on a large scale by Messrs. Bell Brothers, in the north of England, and the following results have been published by their colliery viewer, Mr. A. L.

Steavenson.¹ Not fewer than thirty-six ovens of different shapes and sizes, on Pernolet's system, were tried; but the round or beehive-shaped, about 11 feet in diameter, was found to be the best, as it is alleged to be also for the old system of coking, because, we are informed, such an oven "affords the least possible side-coke, greatest concentration of heat, with the least tendency to wear itself out by contraction and expansion from its frequent cooling and re-heating." The ovens were fitted with iron doors, carefully luted with clay, so that no atmospheric air could enter. The volatile products of carbonization escaped through a cast-iron pipe inserted in the dome of the oven, and passed thence through a long range of similar pipes into condensers, also consisting of a series of similar pipes, each 40 ft. long and 1 ft. 9 in. in diameter. These pipes, to the number of five, were fixed horizontally, at short intervals, above each other, and there were three series of pipes, side by side, or fifteen in all, in what is termed a block. This system of pipes communicated with a tower, filled with coke, 13 ft. high and 4 ft. in diameter (inside measure), from which proceeded a horizontal main pipe, connected by descending branch pipes, with two tar-wells underneath, each 14 ft. 7.5 in. long, 10 ft. wide, and 12 ft. deep (inside measure), and communicating with a number of ovens. There were two such condensing systems, as above described, for the whole series of ovens. The volatile products of carbonization, in their course to the ovens, deposited tar and ammoniacal liquor, which ran into the tar-wells. Under the ovens only refuse small coke was burnt.

Carbonization, it will be seen, proceeds from below upwards, and, according to Steavenson, the uppermost coal is liable to become what he terms "roasted" and incapable of yielding good coke. It has been previously shown (see p. 308) that when caking coal is exposed to a temperature of about 300° C. for a certain time, it does not, on being subsequently heated to redness, produce a firmly coherent coke; and roasting the coal, under the circumstances above mentioned, might be supposed to mean depriving it of its caking property by heating it to too low a temperature at first. But it can hardly mean this, for Steavenson says, "to prevent the top coals being roasted before the heat reaches them, it is necessary to keep the top coals as cool as possible." What it does mean I know not. With a view to prevent "roasting," domes of different heights were tried, and the best yield was obtained from the large round oven, the dome of which was 1 ft. 10 in. higher than that of the other ovens. The yield from the 36 ovens in one week was 249.42 tons of coke from 367.87 tons of coal, or nearly 68 per cent.; tar (assumed to be anhydrous) 2.4 per cent.; and ammoniacal liquor 5.2 per cent. But in addition there were 3½ per cent. of refuse coke, termed "black ends," which were burnt on the grates under the ovens, and loss estimated at 2½ per cent. exclusive of 18 per cent. of gas conveyed into the fire-

¹ Transactions of the North of England Institute of Mining and Mechanical Engineers, 1873, xxii. 3 *et seq.* The paper is illustrated with lithographs to scale.

place under the ovens. During one period of five months, from 7591 tons of coal 70,676 gallons of ammoniacal liquor were obtained, which yielded 14 tons of sulphate of ammonia, or 0.185 ton per 100 tons of coal. The composition of the coal operated upon is not given.

The cost of making the coke was "not greatly different from that of the common oven, so far as mere labour is concerned; but there is an additional cost in closing the doors and luting them with clay, in the attention to the fires on the grates, the superintendence of the gas arrangements, and separation of the 'black ends' and inferior coke, amounting to, perhaps, 3 pence per ton of coke." The Pernolet system was abandoned by Messrs. Bell Brothers, notwithstanding the apparently satisfactory results above reported; and the reasons assigned for this are, the inferior quality of the coke, and the greater cost of maintenance of the ovens. On this subject it is desirable that the judgment of Steavenson, under whose direction, it will be remembered, the above-mentioned trials were made, should be presented to the reader in his own words, which are as follow:—

"The coke, under ordinary circumstances, was soft, and showed a large number of 'black ends,' which alone was sufficient to condemn it; but for two years or more, every pains was taken, and every possible condition of oven was tried, to make a reasonably good coke, and yet avoid an expensive outlay for repairs; with what success may be seen, when it is stated that on an average each oven was out for repair during a period of six weeks in one year. Indeed, every four months each and every oven required a thorough repair. The flue walls were built of gannister bricks (i.e. Dinas bricks), and these, by the intensity of the heat, gave way, and had to be hacked out piecemeal; the alternative was this, make a good or fair coke, and burn the oven down in a very short time, or save the oven and make soft coke. In France, the author understands, these conditions are not so marked, which may be attributed to a difference in the heating powers of the coals and gas; there they require a thorough repair about once a year."

What the heating power of the coals has to do with the matter, it is difficult to understand, seeing that carbonization is effected by heating the ovens on the outside; and, with respect to the gas, nothing assuredly could be easier than to vary the quantity burnt according to the temperature required.

My friend Mr. Isaac Lowthian Bell, one of the firm of Bell Brothers, has recently (August 17, 1874) favoured me with the following remarks on the Pernolet oven:—"In reference to the ovens we erected for obtaining coke by close distillation, I find the yield was about 64 tons of coke from every 100 tons of coal employed. In addition to this we obtained close on 6 gallons of tar per ton of coal treated in the ovens, along with a certain quantity of ammoniacal water, of which we have not a very accurate account. The yield of coke I consider fully 5 per cent. better than that of the ordinary ovens, in which the evolved gases are burnt inside the oven instead of outside,

as happens in the oven in question. This and the tar no doubt are important matters; but the expense of manufacturing the brick-work and general increase of labour, etc., went far to absorb all the gain in these respects. There is a second disadvantage which I have found to attend more or less all ovens from which a better yield of coke is obtained from the coal, namely, the inferiority of the product for iron-smelting purposes.

"It is generally allowed by smelters that hard coke is best suited for these purposes, and I have sought to explain this, in my published investigations, by the greater power of hard over softer coke of resisting at elevated temperatures the action of carbonic acid in the higher region of the blast-furnace. It is clear that if carbonic acid resulting from the action of carbonic oxide on sesquioxide of iron is reduced to carbonic oxide by contact with carbon,² you not only have a cooling action set up, but carbon, which otherwise would reach the hearth, is volatilized, where it renders no service. Now, so far as my observation enables me to judge, there is less of this soft coke in that manufactured in the ordinary oven than in these more refined structures. As a consequence, and somewhat against my inclination, I have been led to return to the old-fashioned plan, although its use is attended with a waste of fuel. Against this loss, however, we may now set the application of the heated gases, which formerly escaped into the air, or at all events were not utilized for obtaining steam for the general purposes of the colliery."

According to Steavenson the Wigan Coal and Iron Company have had one hundred and twenty of the Pernolet ovens in operation, with every appliance for collecting both tar, ammonia, and coal oils, but have given up the collection of the latter. The ovens are exhausted and the volatile products driven by pumps through condensing apparatus, consisting of eight vertical vessels about 15 ft. high and 5 ft. in diameter, into which water is pumped and used over again until it acquires the proper degree of strength. Part of the gas is withdrawn for the purpose of illumination, while the rest is burnt under the ovens. The products of combustion from the fire-place ascend and pass round the top of the oven, contrary to the opinion of Steavenson that it is necessary to keep the top cool. The charge for an oven 11 feet in diameter is 5 tons of small washed coals. The yield of coke is about 60 per cent., which is stated to be good for the coal of the district, and that of sulphate of ammonia 0.26 per cent., or, say, a quarter of a ton per 100 tons of coal.³

The evidence which has now been advanced concerning the working of the Pernolet oven is not a little conflicting, and should serve as a warning to persons who are apt to be led away by the representations not only of inventors, but of disinterested practical men, concerning the value of alleged improvements.

² Mr. Bell, in his letter to me on the Pernolet oven, has used symbols to express this reaction.

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³ Steavenson visited the Wigan Coal and Iron Company's works, and therefore wrote from personal examination.

2 K

PEAT-CHARCOAL.

The charcoal produced by the carbonization of ordinary *air-dried peat* is very friable and porous; it takes fire very readily, and when ignited nearly always continues to burn until its carbonaceous matter is wholly consumed; it scintillates in a remarkable degree when burnt in a smith's fire; its extinction when in mass is difficult, and hence this is the troublesome part of its manufacture by the usual method of carbonization in piles; and it is so little coherent that it cannot be conveyed without much of it being crushed to dust.¹ It is, indeed, so tender as to be incapable of supporting even moderate pressure without crumbling, and on that account alone would be unfit for high blast-furnaces, in which the contents, especially in the lower part, have to bear the weight of a heavy overlying mass. The reason is that much of the charcoal would be crushed to powder, which would obstruct the upward course of the air injected into such furnaces near the bottom; and, consequently, would either prevent the development of sufficient heat or even extinguish the fire. But in low small furnaces, and in hearths like that of a blacksmith, as the tenderness of the fuel is not a matter of so much importance, peat-charcoal of good quality might be used. It is stated that, owing to its brittleness, water cannot be used for quenching peat-charcoal.

HISTORICAL NOTICE CONCERNING PEAT-CHARCOAL.
(CHARRING IN PILES.)

During the last two centuries or more, many attempts have been made to substitute peat-charcoal, made from ordinary air-dried peat, for wood-charcoal in the smelting of iron in high blast-furnaces, but in no instance, so far as I am aware, with complete success,—a result which, from the foregoing considerations, might have been anticipated. It is recorded that peat-charcoal was made in the Harz in 1735, and successfully applied on a large scale; and that it was used in the production of iron, but whether in the smelting or manufacture of that metal, or in both, it is not stated. But this application was, it is alleged, disparaged by one class of persons simply on account of its novelty, and by another class because they were interested in keeping up the price of wood; and the general adoption of peat-charcoal would lessen the demand for wood-charcoal and lower its price. It was even maintained that peat-charcoal was unfit for iron-making, because, during its combustion, it would evolve an acid vapour which would attack the metal and injure its quality!² We may, however, reasonably conclude that neither prejudice nor interested opposition could long have prevented its application in iron-making, and many

¹ Chevalier, *Sur la Carbonisation de la Tourbe à Crouy-sur-Ourcq*; *Annales des Mines*, s. 2, 1829, v. 223.

² Vogel, *Der Torf, seine Natur und Bedeutung*, p. 105.

other metallurgical operations, if it had not been found in practice inferior in one respect or other to other kinds of fuel. The literature relating to peat-charcoal is extensive as well as interesting, and the following historical details on the subject may, it is conceived, be acceptable to the reader.

The earliest English patent, in which the charring of peat is mentioned, is that granted in 1620 to Sir William St. John, Sir Giles Mompesson, and others;³ but no specification of this patent was enrolled. The exclusive right "to charke or otherwise to converte into charkcole" every kind of coal, peat, or other "combustable matter of what nature or qualetie soever the same be (wood onelie excepted)," was given to those persons for the term of twenty-one years. No method of charring is mentioned; and as only one method of making charcoal was then practised, it may be fairly inferred that it was proposed to treat peat in the same manner as wood when it is converted into charcoal. More than a century afterwards, namely in 1727, a patent was granted to William Fallowfield for the use of charred peat in the smelting and manufacture of iron.⁴ In Boate's "Natural History of Ireland," published in 1726, there is a paper on "The Bogs and Loughs of Ireland," which Mr. William King communicated to the Royal Society of Dublin, and in which is the following passage:—"I have seen turf charc'd, it serves to work iron, and as I have been inform'd, will serve to make it in a bloomery or iron-work: turf charc'd I reckon the sweetest and wholesomest fire that can be; fitter for a chamber, and cónsumptive people, than either wood, stone-coal or charcoal" (p. 109).

There are several excellent papers on peat-charcoal in the first volume of the "Journal des Mines," and amongst them one by Blavier,⁵ containing a history of the art of charring peat, from which much of the following information has been derived. Peat-charcoal was first used in 1560 in Saxony for the melting of metals.⁶ In 1626 Charles Lamberville, a Frenchman, published a little work, with the title, "Discours politiques et oeconomiques;" and in 1631 a second and enlarged edition of it, with the title, "Œconomie ou Mesnage des Terres inutiles propres à brusler et à faire Charbon de Forge;" from which works it appears that the author was not only aware of the existence of most of the turbaries in France, but brought over from Holland and Denmark workmen and tools for working them; and further, that "going beyond foreign invention, he found the means of converting certain kinds of peat into charcoal, to be used in forges as a substitute for pit-coal (*charbon de pierre*), which foreigners sold on

³ A.D. 1620, April 25, No. 15. Abridgments of Specifications relating to the Preparation and Combustion of Fuel, 1867, p. 1.

⁴ Specification, A.D. 1727, February 9, No. 490. Abridgments of the Specifications relating to the Manufacture of Iron and Steel, 1858, p. 3.

⁵ Considérations sur le Charbonage de la Tourbe, l'Histoire de cet Art, ses

Procédés et son Utilité: Journal des Mines, i. (part 2), 19 *et seq.* The volume was published in An 3 of the Republic, i.e. during 1794 or 1795.

⁶ The authority quoted for this statement is a work which I have not seen, namely, "Essai sur les Moyens de faire un meilleur Usage de la Tourbe;" Altenbourg, 1781.

their own terms to the French (*au prix que bon leur sembloit*).¹ It was admitted that while light peat had not sufficient coherence (*n'avoient pas assez de lien*) to make charcoal, the heavier kinds were fit for that purpose. A blacksmith of Corbeil declared "that the black earth of Villabé, between Corbeil and Villeroi, prepared by Lamberville, yielded charcoal, which being applied and blown upon the iron, the latter sweated and welded, so that, consequently, the charcoal of the said peat-earth might be used for forges." Similar experimental evidence as to the value of this fuel in the working of iron was obtained from other practical persons; and it is stated that "although it is less heavy than the pit-coal of England and of Scotland, and a fourth more of it is required, yet by means of it iron has been heated to redness, and made to sweat and weld; and that it may be used for all kinds of smith's work, keeping up the fire much better than the coal of England and of Scotland; that it has no bad smell, nor does it produce so much smoke or such black smoke as that coal." Lamberville does not state how he made his charcoal; but it is reasonably conjectured by Blavier that he adopted the same process as that of wood-charcoal burners, namely, charring in circular piles.

Patin, a doctor of the medical faculty of Paris, published a treatise upon peat in 1673, in which he mentions the use of peat-charcoal amongst the Dutch. Thus he writes, "With regard to the charcoal of peats, the Dutch have a bad custom of extinguishing it, because they render its fumes more pernicious. Their bakers, confectioners, and other artizans, after having ignited (*allumé*) their peats to the degree which they judge proper for making charcoal, which to them moreover is more precious than the peats themselves, collect them in pots, and, after having covered them, they stop up all openings to them (*ils embouchent toutes leurs entrées*), however small they may be, with wet cloths, so that, having no longer passages for their exhalation, the bituminous vapours remain not only attached to them, but enclosed even in the substance, which renders them injurious to health."¹

With respect to the method of charring peat in the same manner as wood in circular piles, Blavier quotes the following remarks communicated to what was then termed the "Agence des Mines" (at a later period the *École des Mines*) by Ribaucourt:—"No consideration had been given to the great contraction which peat undergoes, on its being deprived of its volatile principles, and especially of the enormous quantity of water which it contains, whereby the sinking down of the pile often occurs, and makes it necessary to cover it again with fresh earth before carbonization is completed; whence it results that the charcoal obtained by this process is unequal in quality, and is mixed with breeze and imperfectly charred pieces. Moreover an infinite number of fissures is formed in every part of the cover, which it requires care and constant labour to stop up, very greatly pro-

¹ *Traité des Tourbes combustibles*, par Charles Patin, Docteur Régent en la Faculté de Médecine de Paris: Paris, 1668, p. 79. The passage is literally

translated. It is necessary to add that, at the time in question, charcoal of whatever kind was supposed mainly to consist of bitumen and sulphur.

longing the extinction and complete cooling of the mass."⁸ Further, it was asserted by Guettard that too much peat was burnt to waste, and the charcoal thereby rendered too costly. But, notwithstanding the disadvantages of this method of charring peat, it seems to have been the only one practised for a considerable period. Carlowitz announced so long ago as 1712 that peat was charred in Germany in circular piles in the same manner as wood;⁹ and according to a statement of Pelouze, published in 1842, peat-charcoal continued to be so made in all the countries of the north.¹ In the district of Wittgenstein the piles of peat were made only 12 feet in diameter, and 3½ feet high at the most; and care was taken to keep them dry by placing them under a shed where the air circulated freely. The charcoal obtained by this process was always very friable, could not bear transport, and became much deteriorated by exposure to damp.²

CHARRING IN OPEN KILNS.

In 1761 Guettard published a description of the "furnaces" in use at the turbaries of Villeroi for making peat-charcoal. They were in the form of an inverted cone, and probably resembled the construction shown in fig. 44, p. 372 of this volume. On one side is a doorway, from 4 to 5 feet high, and about 2 feet wide. Towards the base of the cone is an arched floor to support the peat, with holes in it for the passage of air; underneath is put the little fire needful for igniting the peat; when the latter is sufficiently lighted, the opening communicating with the external air is closed, and the doorway is built up with bricks. The kiln after having been filled with peat is covered with earth and left to burn; gradually the whole mass sinks down, and when no more smoke is emitted the process is considered as ended. When the charring is well done, there ought to be no ashes, or only very little upon the floor; and the charcoal should be very black and sonorous. At least eight days were required for charring in such a kiln; but not more than two or three days by the method usual in making wood-charcoal.

Carnolle invented a kind of kiln which differed but little from that of Guettard: it was in use in 1787. It was 15 feet in diameter and 3½ feet high. At 6 inches from the ground there is an iron grate supported on bricks placed at intervals. The peats when well air-dried are thrown in up to the height of the walls, and above that height are piled so as to form a conical stack, which is covered first with alightly wetted straw and then with a mortar of earth and water. The kiln is ignited through four small openings, 6 or 7 inches long, made on a level with the ground. Between these openings four others are made 2 feet from the ground, which serve for letting in air when considered necessary, and for igniting the

⁸ Journal des Mines, i. (part 2), 22.

⁹ Vogel, Der Torf, seine Natur und Bedeutung, p. 105.

¹ Traité méthodique de la Fabrication

du Coke et du Charbon de Tourbe, par M. Pelouze père, p. 81; Paris, 1842.

² Journal des Mines, i. (part 2), 23.

mass equally throughout. After the fire has reached the conical part of the pile, this part sinks down on itself and becomes fissured, when sand or wet earth is thrown over it. As soon as the conical part has quite sunk to the level of the walls of the kiln, it is covered with 5 or 6 inches of earth or sand, and all the vents are stopped up in order to extinguish the charcoal. The kiln is left in this state during four days, after which the openings or air-passages at the bottom are unstopped so as to let air into the interior of the mass of charcoal. It is left during 12 hours in this state, after which the air-passages are re-stopped, in order four days subsequently to withdraw the charcoal, which is bright and sonorous, and has kept the form of the original peats. According to the inventor, 30 sacks of peats should yield 20 sacks of charcoal; but a disinterested witness of experiments in such a kiln asserted that the yield in volume was only about half that of the peat.

CHARRING IN PITS.

Peat has been charred in pits much in the same way as in the Chinese process of making wood-charcoal, of which an account has been previously given in this volume (see p. 384).³ The invention of this method is attributed to a Frenchman, named Baillet, and is said to have been practised on Chatmoss and Bartonmoss, in Lancashire. The pit is described as slightly conical, 3 metres deep and 4 metres wide. It should be made as solid as possible in the interior by stamping the earth. Round the circumference, which is of brick, eight clay pipes lead to the bottom for supplying air to sustain combustion. The pit is closed by a movable convex cover of sheet-iron, like a common dish-cover; in the top is a hole, fitted with a movable iron stopper, and there are four vents round the border. Below the surface of the ground there is a pipe communicating with the upper part of the pit, and with a brick tank connected with a series of vessels for the reception of tar or other condensable products. The smoke traverses the pipe only when these products are being collected; otherwise, it escapes through the four holes in the border of the cover. When the pit is dry, it is charged with peat, taking care to leave at the bottom horizontal channels, radiating in the direction of the air-pipes: in the centre these channels communicate with a vertical chimney, made by stacking the peat round three posts previously inserted, and, after charging, withdrawing them. After the peat has been ignited at the bottom, the cover is dropped over the pit and is itself covered with sods. The vents are opened more or less according to the nature of the smoke, which escapes from them. The process lasts from 24 to 36 hours before withdrawing the charcoal. The best black peat is stated to yield half its weight of charcoal, and light peat a third.

³ A detailed account of such a process will be found in Pelouze's "*Traité méthodique de la Fabrication du Coke et du Charbon de Tourbe*," p. 84; Paris, 1842.

See also the French translation of the first edition of this volume, by MM. Petitgand and Ronna, p. 405.

CHARRING IN OVENS.

The ill-success of the primitive method of charring peat, like wood, in piles, was attributed to want of consistency and solidity in the apparatus; and hence arose the notion that by enclosing the peat in a solid structure, all the disadvantages above specified would be avoided, and perfect charcoal obtained. Accordingly, with this view various kinds of ovens were from time to time contrived, of some of which only I propose to indicate the construction.

The first oven on this principle is stated to have been invented by Lange, and was in operation on the Brocken, in the Harz, in 1745. It consists of a chamber of iron, cylindrical to about two-thirds of its height, and conical the upper or remaining third, which is formed in three pieces fitting closely upon each other successively. It rests on an iron bed-plate, containing a rectangular opening, over which iron bars are laid to form a grate. The bed-plate rests upon a chamber of brickwork, open at the top and in front, where it can be closed by a door: the floor of the chamber is inclined from back to front. This chamber is intended for a fire-place for wood fuel. Peats are carefully laid over the grate so as not to stop the draught upwards from the fire-place. The kiln is then filled through the top, and a wood-fire is made in the fire-place. When the peat has become well ignited the fire-place is closed with an iron door, which is luted round with clay. The peat is thus gradually heated to redness, and shrinks about one-third in volume. Fresh peat is now thrown in at the top, and this course is repeated until the entire contents of the kiln become red-hot. As soon as smoke ceases to escape, the top is covered with an iron plate and luted. The total charge is about 700 peats, and the process lasts from 12 to 14 hours, and about 12 hours are required for cooling. The charcoal is withdrawn through the opening in the bed-plate. The charcoal is brittle and in small pieces, much waste-stuff is formed, and there is great loss, as the lower part of the charcoal is consumed before the upper part is properly formed. There were forty of such kilns erected on the Brocken, in the principality of Wernigerode, at a cost exceeding 100,000 Thalers. In 1749, that is, four years after their introduction, this process "was near its end, maintained itself for some time afterwards, and was at last wholly abandoned."⁴ The peat-charcoal was used in the smelting of iron ores.⁵ Dietrich, it is reported, saw these kilns in action on the Harz in 1781.⁶ One objection to such kilns is, according to Pfeiffer, that the volatile products of the carbonization of peat corrode and destroy the ironwork, an objection which Cramer proposed to obviate by building them of stone lined internally with cement in order to make them air-tight.

Kilns of brick or stone were now introduced: they were circular and in mode of action similar to Lange's kiln above described, but

⁴ Vogel, *Der Torf, seine Natur und Bedeutung*, pp. 108-110. This kiln has been often described, but I have chiefly availed myself of Vogel's description of

it, which is illustrated by a woodcut of the kiln in vertical section.

⁵ *Journal des Mines*, i. (part 2), 26.

⁶ *Idem*, i. (part 2), 24.

much more capacious. By way of example, a short description of one of the most approved of such kilns is here presented.

• It consists of a cylindrical chamber, which is flat at the bottom and arched over at the top, is 9 feet high, and 5 feet in diameter in the clear; it is surrounded by double walls, 15 inches thick, and the same distance apart from each other. These walls are tied together at intervals by stones, crossing the annular space between the walls, and this space is filled with ashes or sand. The outer wall is carried up vertically as high as the outside of the top of the dome resting on the inner wall, which is, therefore, lower than the outer wall. In the crown of the dome is a round opening, provided with an iron cover. Between the floor of the chamber and to about one-fifth of the height of the axis of the chamber, inside measure, three rows of iron pipes—the lowest row just above the level of the floor, and the next row midway between the lowest and uppermost rows—pass horizontally through the walls, with their axes convergent towards the axis of the oven: they do not protrude beyond either the inside or outside of the oven, and they are arranged quincuncially, so that only the lowest and uppermost pipes are, respectively, over each other. These pipes are intended to serve as vents for the admission of air into the oven; and as any or all of them may be opened or closed at will, the quantity of air admitted is under perfect control. On one side of the oven, from the level of the floor to a little above the uppermost row of pipes, is a doorway. The free space between the doorway and the exterior of the outer wall may be made to serve the purpose of a fire-place, by placing in front an iron plate, inclining outwards, and resting on the outer edge of the floor of this space, and fixing a temporary grate about midway between the bottom and top of the space. Through the doorway the peat is ignited, and charcoal withdrawn. It is easy to prevent any air from entering through the doorway, by adjusting the door and throwing up sand against it. In charging the oven, peat, which is presumed to be well air-dried, is first introduced through the doorway, and carefully spread, taking care to leave a large channel from the doorway, and several small side channels from the centre of the oven in the direction of the vents in the walls. When peat has been put in up to the top of the doorway, the remainder is thrown in through the hole in the crown of the dome. The oven is now lighted by making a fire on the grate, and as soon as the peat in the interior is seen to be kindled, the doorway is closed; and the vents also are gradually stopped, as incandescence extends upwards. When smoke ceases to escape from the top of the oven, the hole in the latter is closed. Carbonization is generally completed in 48 hours, and from 6 to 8 days are required for cooling.⁷

⁷ Vogel, *Der Torf, seine Natur und Bedeutung*, pp. 113-115. A description of a kiln similar in principle to that which is above described, and which was in action at Rothau, in the department of the Vosges, until recently belonging

to France, was published by M. Bineau, in the *Annales des Mines*, a. 2, 1829, v. 211. The title of his paper is, "Description du Procédé que l'on suit à Rothau pour carboniser la Tourbe."

CHARRING IN OVENS FROM ABOVE DOWNWARDS.

In all the foregoing methods of making peat-charcoal, charring has proceeded from below upwards, and in no instance could the result be regarded as satisfactory. On this subject Vogel remarks as follows:—"By more accurately observing piles and ovens of every kind, in which peat is stacked to the height of several feet and ignited at the bottom, it was very soon found in practice that the lowermost and first-ignited layers of peat suffer extraordinarily from the weight of the overlying mass of peat, being squeezed together by the softening of the peat at a red-heat, and that much small charcoal, ashes, and waste are produced. It was very early sought to obviate this evil by the construction of ovens in which the peat should be ignited at the top and the lowermost layers be the last charred, so that these no longer should have to bear the weight of the overlying uncharred layers of peat. The oldest known oven on this principle is that of Hahnemann."^a

Hahnemann's oven consists of a circular shaft of brick- or stonework, 16 feet high and 7 feet in diameter in the clear. The walls gradually diminish in thickness from 2 feet at the bottom to 10 inches at the top. The shaft rests upon a solidly-built foundation. The floor is somewhat arched, with the convexity upwards, and on one side is an opening for withdrawing the charcoal. In the circumference of the floor is a gutter made of glazed tiles, from which a glazed clay-pipe passes, with a slight inclination downwards, through the wall, and communicates with a tank for the reception of any liquid which may be condensed. On the middle of the floor stands a vertical clay-pipe glazed internally, 19 feet high and 16 inches wide, and in which, near and round its base, are several holes, the total area of which should at least equal that of the cross-section of the pipe. Before charging, the opening at the bottom of the oven is built up; then the shaft is filled with peats, and on the top are laid twigs and charcoal, which are lighted. When the peat at the top has become regularly kindled, the open space round the chimney is closed, so that the smoke is compelled to descend through the peat and pass into the chimney near its base, and thence rise into the atmosphere. As soon as the contents have become red-hot at the bottom of the shaft, all openings are carefully closed and luted, and the oven is left to cool.^b Some air, it is presumed, must find its way into the top of the oven, after it is directed to be closed; for, otherwise, charring could not long afterwards continue.

Vogel reports that a portable oven on the same principle as that last described was shown by Moreau and Son at the Exhibition in Paris, in 1855. It was 8 feet in diameter and nearly as high, and had a chimney 15 feet high. It was said to be capable of charring 3000 kilogrammes of peat in twenty-four hours, with a yield by

^a Der Torf, seiner Natur und Bedeutung, p. 117.

^b Idem, pp. 117-119.

weight of from 37 to 40 per cent. Samples of peat-charcoal produced in this oven were exhibited, and are pronounced by Vogel to have been good, but tender, as they were only obtained from common peat.¹

Vogel states that, long before seeing this oven, he made numerous experiments in an exactly similar oven, and had got good results according to the quality of the peat which he operated upon; but that the charcoal, compared with that made from peat in retorts, was still too tender, not to lead to the wish for a method by which better results might be obtained. He adds that his experiments on charring peat downwards have, in his judgment, conclusively proved the superiority of this method, and that, for the future, experiments only on this principle should be made.

CHARRING IN OVENS BY THE INTRODUCTION OF HOT GASES.

A method of charring wood at Dalfors, in Sweden, by means of gaseous products of the combustion of wood in a separate fire-place, has been previously described in this volume (see p. 386). These products pass directly into an oven containing the wood to be carbonized, and, having been made to circulate through every part of the oven as equably as practicable, escape therefrom along with the volatile products evolved from the wood undergoing carbonization. One condition of obvious importance in this method is that the gaseous products of combustion on leaving the fire-place should contain as little free oxygen as possible; for free oxygen within the oven would cause the burning of charcoal to waste. But it would be impossible to prevent some loss of charcoal, if the contents of the oven should in any part become sufficiently heated to be oxidized by carbonic acid, with the formation of carbonic oxide, or by steam, with the formation of carbonic oxide and hydrogen; because the gaseous products of the combustion of the wood in the fire-place contain both carbonic acid and steam. It is true that a fire-place might be so constructed as to convert the carbon wholly into carbonic oxide; but in that case a much greater quantity of wood would be required to effect carbonization, owing to the fact that carbon when converted into carbonic oxide evolves so much less heat than when it is converted into carbonic acid.

In Echement's process of making brown charcoal, which has also been previously described in this volume (see p. 410), the same principle, at least in a certain degree, is applied as in that of the Dalfors oven. On the same principle also, it is stated that Weber makes peat-charcoal at Staltach. For this purpose a cylinder of sheet-iron, surrounded by masonry, is used. Below, it rests on a grating of stout iron wire; and above, it has a cover, which may be raised by a pulley. On one side is attached a small furnace, the draught of

¹ A fuller description of this oven will be found in the French translation of the first edition of this volume.

which is kept up by mechanical exhaustion, and the flame and hot gases from it, which are said to contain no free oxygen, play upon and char the peat. The construction of the furnace is such that the sticks of wood, which are used for fuel, are supported at their ends on shoulders in the brickwork, and the draught from the fire is downwards instead of upwards. Air is admitted to the descending flame to burn any combustible gas or vapour in the products from the fire, care being taken not to admit more than suffices for that purpose; which is done by means of a sliding damper. In a similar manner the supply of air to the furnace above is also regulated. The wood used for fuel is cut of the same length, and itself forms a grate; for iron bars could not be used, as they would soon burn away. In addition, means are provided for admitting air to the bits of carbonized wood which may drop from the fire, the supply of which air is regulated by means of a damper. The highly-heated gaseous products of combustion enter the cylinder filled with peat near its top, and are distributed by pipes, and, passing off through the grating at the bottom, enter the surrounding brick mantle. Before reaching the exhauster, they pass through a "cooler" in which a quantity of tar and pyroligneous acid is collected. The oven is 15 feet in diameter and $3\frac{1}{2}$ feet high: and 528 cubic feet of peat may be charred in it in 15 hours. The wood fire-place is 2 feet in section, and consumed for that quantity of peat $3\frac{1}{2}$ cwt. of wood. The yield of charcoal is stated to be nearly 50 per cent. of the weight of the peat.² When we consider the ultimate composition of peat, it is not easy to understand how, supposing carbonization to be thoroughly effected, so large a yield as that should be possible, even from the peat prepared at Staltach in the manner previously described in this volume. In a description of this method of making peat-charcoal by Petitgand and Honna, it is stated that the fuel is peat; that the resulting charcoal is hard, bright, sonorous, and denser than wood-charcoal; and that the peat yields about half its weight, and three-fourths of its volume of charcoal. The charcoal is said to be used in various local works, forges, furnaces for metallurgical operations, etc.³

Vogel has experimented on the making of peat-charcoal on the same principle, and his results, he reports, were so satisfactory as "truly to surprise him;"⁴ but his experiments were only on a small scale. Whether he has had the opportunity of repeating them on a large scale, as he desired, I do not know.

It is suggested by Vogel that peat should be burnt at the bottom of a chamber, resembling that marked A, shown in fig. 101, on p. 517 *infra*, but without using a blast; that the products of combustion should pass directly into the bottom of a contiguous vertical chamber filled with peats, each chamber having a hopper at the top for charging; the second chamber also having one or

² Johnson, *Peat and its Uses*, pp. 157-161.

tion of this volume, p. 407.

³ French translation of the first edi-

⁴ *Der Torf, seine Natur und Bedeutung*, p. 133.

more openings immediately below the hopper for the exit of the gases and accompanying volatile products disengaged from the charring peat, and an opening on one side near the bottom for withdrawing the charcoal. This chamber, it will be perceived, is intended to act like a chimney, and cause the gaseous products of combustion to ascend by exhaustion through the peats. It is hardly necessary to add that the opening for withdrawing the peat is to be kept closed during carbonization. Any kind of fuel may be used in the first chamber. It is reported that the principle was in operation in 1858, at one peat-manufacturing establishment in Bavaria, though the apparatus for applying it differed widely from that above indicated. The peat-charcoal so made is reported to be of very excellent quality (*von ganz ausgezeichnete Qualität*).⁵

Another proposed method of charring peat is to apply the heat resulting from the combustion of the waste-gas of high smelting furnaces (such as those in which pig-iron is formed), or the gas from a common gas-producer, the charring chamber having the same construction as that last described. The combustion of the gas is to be sustained by the mechanical injection of air into the gas as it escapes from the delivery pipe, just where it enters the charring chamber. Charring by this means is stated to have been successfully carried out in some Swedish smelting-works;⁶ but G. Ekman does not mention the fact in his communication to me in 1872 on "The Use of Peat in Metallurgical Operations in Sweden" (see p. 264 *antea*), as it is probable he would have done if at that date peat-charcoal had been used on any large scale in Sweden.

CHARRING IN CLOSE VESSELS BY EXTERNAL FIRING.

Much attention has been given to the distillation of peat in retorts or muffle-like chambers heated externally, but generally with reference to the collection and utilization of the volatile products, and the resulting charcoal has only been considered as an accessory product of secondary value. Various ingenious arrangements have been contrived with this object, which will be found described in Vogel's treatise, in periodicals, and in works on chemical technology; and to such sources the reader is referred for information, as the subject is beyond the scope of this work. A short description, however, of a closed oven, in which the charcoal is the chief product obtained, will be inserted here.

In an official report on the Vienna Universal Exhibition in 1873 will be found a description of one of the most recently invented closed ovens, the inventor being Lottmann, of Chlumetz, in Bohemia. This oven is an arched muffle-like chamber, heated by two fires, one on each side, and by a third fire at one end under the floor. The central fire-place opens into a flue running under the floor to the chimney at the opposite end of the oven. In the top of this flue are

⁵ Vogel, *Der Torf, seine Natur und Bedeutung*, p. 135.

⁶ *Idem*, p. 184.

inserted two syphon-like sets of cast-iron pipes, of which the legs are parallel, and which rise within the oven to about half of its height. Midway between the legs of each of these sets of pipes, the flue is stopped by a vertical partition, by which means the gases from the fire-place are made to pass in their course to the chimney through all the four legs of the two syphon-like sets of pipes in succession. Provision is made for collecting the liquid products evolved from the peat during its carbonization. The peat which is charred in this oven is hand-cut air-dried peat. An oven contains about 20 cubic metres of such peat, of which 5 metres are introduced at two or three intervals subsequently to the first charging. The process lasts from 50 to 60 hours, according to the moistness of the peat. The yield is from 8 to 9 cubic metres of charcoal, and about 10 cubic metres of waste peat are consumed in firing. The cost of winning and charring the peat, besides the maintenance and management of the ovens, is stated to amount to 2 florins 85 kreuzers, Austrian currency (= 5s. 2½d.), per cubic metre of charcoal. Fifteen of these kilns have been regularly at work at Josefstadt, in Bohemia, since 1860. Lottmann states that he obtains better charcoal from peat which has been pulped and moulded, but that up to the present time (1874) he has found it to be too costly.⁷

CHARRING IN CLOSE VESSELS BY SUPERHEATED STEAM.*

The charring of peat by superheated steam has been tried, and reported to be successful. The following account of this process appeared in the first edition of this volume:—

Mr. Vignoles, the civil engineer, proposed a method in 1849 for charring peat by steam superheated to about the melting-point of tin, or even lead. Blocks of peat, formed as previously described on p. 264, are put into large cylindrical iron vessels, into which steam at from 45 to 60 lbs. pressure per square inch is admitted, after having been superheated by traversing tubes heated to bright redness. Mr. Vignoles stated that he had proved the practicability of the process on the large scale, at an expense of some thousands of pounds; and he gave numerous elaborate calculations of its cost. The charcoal or "coke" was considered to be equal to gas-coke, and the total cost in Ireland of peat-charcoal made by this process was estimated at 8s. 4d. per ton, exclusive of any profit and of payment for patent rights. Mr. Vignoles indulged in sanguine anticipations respecting the effect of his invention upon Ireland. He thus wrote:—"This new method of obtaining a coke (which is peculiarly, perhaps absolutely, free from sulphur), when made from the most compact turf, may be looked forward to for restoring the trade of making iron in several parts of Ireland, for the superior quality of the metal would

⁷ Reports on the Vienna Universal Exhibition of 1873. Presented to both Houses of Parliament. London, 1874, part ii. pp. 308-310. The report on peat is written by Mr. C. Paget, civil engineer.

* On the 19th of June, 1848, Violette presented a memoir to the French Academy of Sciences on the carbonization of wood by superheated steam. *Ann. de Chim. et de Phys.* s. 3, 1848, xxiii. 751.

command in the English market, and *enable it to compete with the best iron from Sweden.*" The italics are mine. I am not aware that Ireland possesses iron-ores which, in respect of quality and abundance, are to be compared with those of Sweden; and I fear that many years will elapse before the restoration of the Irish iron-trade occurs. Mr. Vignoles' process of manufacturing peat-charcoal has never, I believe, been adopted either in Ireland or elsewhere. Sir Robert Kane informed me, in 1861, that the then cost in Ireland of the peat necessary to produce 1 ton of charcoal would exceed by 3s. 8d. the sum stated in Mr. Vignoles' estimate as the total cost of that weight of charcoal; the price of peat being about 4s. per ton, and 3 tons being necessary to furnish 1 ton of charcoal.

In the "Practical Mechanics' Journal" of April 1, 1862, there appeared a notice of the first edition of this volume by the editor, Mr. Robert Mallet, in which some of the statements in the foregoing description of the steam-charring process are said to be incorrect. Mr. Mallet's remarks are as follow:—

"No notice is taken of the simple and excellent kilns for the artificial drying of turf, long in use in North Holland, and described in the Transactions of the Institution of Civil Engineers of Ireland some years ago. Nor are the facts as to Vignoles' Patent, for the carbonization of peat by superheated steam, either fully or correctly given. They happen to be within our own personal knowledge. Vignoles' process was never attempted to be tried in Ireland, no more than the Dutch desiccating kilns recommended by Mallet. Famine and potato rot at that time stopped all that. Vignoles' estimate of cost, however, was true for Ireland at the time it was made; and when Sir R. Kane stated to Dr. Percy in 1861, that the present cost in Ireland, of the peat necessary to produce one ton of peat-charcoal, would exceed by 3s. 8d. the sum stated in Mr. Vignoles' estimate as the total cost of a ton of the charcoal, he should also have stated that wages in Ireland have, since then, more than doubled in value, and that peat there is still collected, stacked, and dried (when it *can* be dried at all) by the old labour-wasting methods. It might be added that Sir R. Kane is himself partly to blame for this absence of all improvement in the preparation of peat in Ireland, by having in a manner, far from personally creditable, attempted to damage the adoption of the Dutch kilns, by enabling Dr. Rees Reece to make some statements with respect to them, which were absolutely and transparently untrue, in his (Sir R. Kane's) report 'On the Nature and Products of the destructive Distillation of Peat,' etc., made as Director of the Museum of Irish Industry in 1851.

* * * * *

"Yet, even to-day, the introduction to Ireland of these Dutch kilns, to make peat preparing, independent of weather, still more, if with the improvements, that Siemens' Patent Furnaces, described in our last part, would admit of being added to them, would mark an epoch in the future supply of fuel in that part of the empire, and reduce its cost most materially, as well as greatly improve its average

quality." [This sentence is given exactly as it appeared in the "Practical Mechanics' Journal."]

"Vignoles' process for carbonization has, as we have said, never been tried in Ireland; but extensive works were erected at Friessac, in Prussia, where large quantities of the peat-coke were made, and sent by the Hamburg and Berlin Railway into the latter city. It was used largely there, for domestic culinary fuel, and also tried for some time upon the railway, for locomotive use. The coke produced was as excellent in quality as could be produced from the very inferior thin peat of Friessac, and when made, there, from some best Irish turf, imported for the experiment, proved still better. Mechanically and financially the process was a complete success.

"The real cause of failure was this: the peat-coke had the property (and all peat-coke has the same, more or less) when heated in becoming ignited, of cracking and falling to pieces; it was also so tender and easily broken, that a few miles' carriage, on the railway or road, reduced a great proportion of it to gross powder. Owing to these causes, the waste was excessive in use, and the fires damped, in consequence of the draught being checked by the small bits of coke, or the latter, with the sharp blast of the locomotive, were driven in masses through the tubes and into the smoke-box."

If I fell into error in stating that Vignoles' process had never been adopted, I am glad to have this opportunity of publishing the above correction by Mr. Mallet. But it is a satisfaction to me that one much more likely to be better informed on the point than myself—I mean Professor Vogel, of Munich, the author of the treatise on Peat which I have so often quoted in this volume, and from which I have derived much instruction—expressed himself as follows in 1858:*

"Wir glauben, ohne der Autorität Vignoles' zu nahe zu treten, einen bescheidenen Zweifel äussern zu dürfen, ob jemals dieses System in der angegebenen Weise im Grossen ausgeführt worden sei oder mit Erfolg ausgeführt werden könne." This sentence may be freely translated as follows:—Without wishing to impugn the authority of Vignoles, we venture modestly to express a doubt whether this system has ever been, or could ever be, carried out on the large scale.

In the Report drawn up by Sir Robert Kane "On the Nature and Products of the Process of the destructive Distillation of Peat, considered specially with reference to its Employment as a Branch of Manufacturing Industry," and presented to both Houses of Parliament, April 8, 1851, a letter from Mr. Rees Reece to Sir Robert, dated March 19, 1851, is inserted, which contains the following passage in reference to the proposal to introduce the Dutch kilns into Ireland:—"I think these facts [which are given in the letter] fully demonstrate that no artificial means can ever be employed to harvest peat; and in reflecting on the various processes that have been proposed for that purpose, how little must the parties have studied the subject: doubt-

* Vogel, Der Torf, seine Natur und Bedeutung, p. 132.

less the best of these is that proposed by Mr. Rogers, which may be said to be a brick machine, with compressing power from an oscillating beam; and probably the most absurd, the turf kiln of Mr. R. Mallet, Ph.D. I have seen some of them on the bog of Allen, one about three miles from *Monastereven*; to suppose that any artificial means of applying peat to evaporate 80 or 84 tons of water, to get 20 or 16 tons of peat, must suppose an arrangement of physical chemistry unknown at present."

YIELD OF PEAT-CHARCOAL.

With regard to the yield of charcoal from peat, numerical statements would be of no practical value, unless they were accompanied with precise information concerning the proportions of water and inorganic matter in the peat operated upon, the ultimate composition of its organic part, and the mode of carbonization adopted.

In the records of the results obtained by charring peat on the large scale, the composition of the charcoal does not appear to have been satisfactorily ascertained, so that it is impossible to judge whether carbonization had been perfectly effected or not.

In the table on p. 206 *antea* is given the percentage of charcoal yielded, in laboratory experiments, by several varieties of peat. The few following additional observations on this subject will suffice. The varieties of peat numbered 4, 5, 6, 7 in the same table (p. 206) yielded the following results to Sir Robert Kane, by the usual methods of desiccation, carbonization in a close vessel, and incineration :—

PERCENTAGE OF WATER, CHARCOAL, VOLATILE MATTER, AND ASH IN AIR-DRIED IRISH PEAT.

| Number. | Water. | Charcoal. | Volatile Matter. | Ash. |
|---------|--------|-----------|------------------|-------|
| 4 | 19·452 | 31·699 | 46·857 | 1·992 |
| 5 | 16·394 | 38·247 | 42·054 | 3·305 |
| 6 | 16·497 | 36·695 | 44·063 | 2·745 |
| 7 | 18·003 | 38·768 | 35·331 | 7·898 |

GENERAL REMARKS ON THE MAKING AND USE OF PEAT-CHARCOAL.

A paper was read before the British Association for the Advancement of Science, in 1865, by D. K. Clark, civil engineer, "On Torbite and its Uses,"—a name given to peat which has been pulped, moulded into blocks, and artificially dried. In this paper it is stated that at Horwich, in Lancashire, there is an establishment where peat is so treated, and the prepared blocks, it is stated, "may either be converted into charcoal for smelting purposes, or may be only partially charred

for use as fuel for generating steam, or in the puddling furnace." It is further stated that "the actual outlay in labour and fuel does not exceed from 10s. to 12s. per ton;" and that "in addition to the economy thus effected in charring, in close ovens, a considerable quantity of valuable chemical products is yielded, as ammonia, acetic acid, pyroxylic spirit, paraffin oils, the sale of which alone will nearly cover the expenses of the whole process. . . . The charcoal made from torbite is extremely dense and pure; its heating and resisting powers have been amply and severely tested, and with the most satisfactory results. At the Horwich works pig-iron has been readily melted in a cupola. About 80 tons of superior iron have been made with it in a small blast-furnace measuring only 6 feet in the boches, and about 26 feet high. The ore smelted was partly red hæmatite and partly Staffordshire, and the quantity of charcoal consumed was 1 ton 11 cwt. to the ton of iron made, but in a larger and better constructed furnace considerably less charcoal will be required. It has also been tried in puddling and air-furnaces with equally good results, considerably improving the quality of the iron melted [1]. For this purpose the fuel was only partially charred, in order not to deprive it of its flame, which is considerably longer than that from coal [1]. Some of the pig-iron made at Horwich was then converted into bars, which were afterwards bent completely double when cold without exhibiting a single flaw. Messrs. Brown and Lenox, in testing this iron for chain-cables, have reported that its strength was proved to be considerably above the average strength of the best brands. . . . In every stage of iron manufacture, and in welding, peat-charcoal is most valuable. At Messrs. Hick and Son's forge, in Bolton, a large mass of iron, about 10 inches square, was heated to a welding heat with peat-charcoal made at Horwich. The time occupied was less than the operation would have taken with coal; the whole mass was equally heated through without the slightest trace of burning on the outside, and in hammering out the mass as much was done with one heating as ordinarily required two heatings to effect."¹

The foregoing extract more resembles in its character the glowing prospectus of a modern limited-liability company, than a grave communication to a society founded for the Advancement of Science. But the British Association has too often been made the vehicle for advertising, free of expense, alleged improvements and inventions. I refrain from offering any comments upon the extract in question, believing that the reader will be able satisfactorily to discharge that duty for himself, and will form the same opinion concerning it as I have. One thing is certain, that as yet the use of peat-charcoal in metallurgical operations in Great Britain is either very restricted or must be kept rigidly secret.

¹ On Torbite (a new Preparation of Peat) and its Uses. By D. K. Clark, C.E. (Read before the British Association.) *The Engineer*, September 15, 1865, p. 175.

In searching through recent German books and journals, I have not found any notices to the effect that the use of peat-charcoal in metallurgical processes has been extended in an important degree. There are, it is true, occasional reports of its successful application, either separately or in admixture with other kinds of fuel, in blast-furnaces. Thus, according to M. Debette, peat-charcoal, made in the Erzgebirge by carbonization in piles, is solid, compact, and very heavy, and is substituted for an equal weight of wood-charcoal in several high blast-furnaces; as it yields only from 3 to 4 per cent. of ash, it must be exceptionally pure.² However, as the practice of metallurgy has so widely extended in recent years, and as the literature on the subject has now become so copious, probably information of an important character may have escaped me. There is an assertion, certainly, which may interest and possibly surprise the Germans; it is as follows:—according to Mr. D. K. Clark, the author of the paper above mentioned, “in Germany peat mixed with wood-charcoal is very extensively used in the production of iron, the peat, as prepared there, not being sufficiently solid to do the work alone, but it is found that *the greater the proportion of peat that can be used the better is the quality of the iron produced.*” The italics are mine. Comment on this statement is unnecessary.

It has been recently announced (1874) that at the Benedicthütte, near Salzburg, peat is charred in circular piles in admixture with wood, and that the charcoal so made is found to be better than wood-charcoal for smiths' fires; and further, that mainly with the view of making peat-charcoal and substituting it for wood-charcoal in iron-smelting, a large company, under the name of the Franco-Austrian Peat Company, has been formed, and is now working in Carinthia.³

At Josefstadt peat-charcoal made in Lottmann's oven is used for iron-smelting in a furnace 36 feet high, and similar in construction to iron-smelting furnaces in which wood-charcoal is the fuel used. The proportion of ore in the charge is said to be the same in furnaces worked with both kinds of charcoal. Generally a mixture of equal parts of peat-charcoal and wood-charcoal is used; but for many weeks a mixture of two-thirds peat-charcoal and one-third wood-charcoal has been used. It is not clearly expressed whether peat-charcoal exclusively is ever used. According to Lottmann “peat-charcoal from stiff resinous peat is, as regards calorific effect and capability of bearing the charge, equal to soft wood-charcoal,” and that “from light fibrous peat is, with respect to the same qualities, as nine to ten.” If by charcoal from “light fibrous peat” is meant that prepared from such peat, without previous pulping and moulding, the statement of Lottmann, that it so nearly equals soft wood-charcoal, is certainly opposed to general experience.

There is a reference in Wagner's Jahresbericht for 1871, xvii. 912,

² French translation of the first edition of this volume, p. 402.

³ Reports on the Vienna Universal Exhibition of 1873. Part ii.

to a description by E. Storkenfeldt and L. Wenström on the making of peat-charcoal in Sweden, dated 1871, which I have not been able to refer to.

PRACTICAL CONCLUSIONS CONCERNING PEAT-CHARCOAL.

From what has been advanced in the foregoing pages on the subject of peat-charcoal, the following conclusions may be drawn for practical guidance:—

I. Peat in its early stage of formation, or that which occurs near the surface of the bog, consisting as it does of only the tangled and but little changed remains of its parent plants, is unsuitable for carbonization in its ordinary air-dried state, because the resulting charcoal has very slight coherence.

II. The converse of the last proposition is therefore true, or, in other words, peat becomes more and more fit for carbonization in proportion to the obliteration of the structure of its parent plants, and to the difference in composition between it and the organic substance of those plants.

III. The denser and more compact the peat is made by pulping and moulding, or otherwise, the more coherent and better, *ceteris paribus*, will be the product of its carbonization. Moist peat is stated not to be suitable for carbonization, because, irrespective of the prolongation of the process from that cause, it produces an enormous quantity of peat-dust.⁴

IV. It is hardly necessary to remark that peat intended for carbonization should contain as little fixed inorganic matter as possible, especially iron-pyrites, when it is desired to use the charcoal in metallurgical operations in which sulphide of iron would be injurious.

V. By a judicious selection of peat and suitable treatment, peat-charcoal might, so far as relates to its capability of producing heat, serve as an efficient fuel in certain metallurgical operations.

VI. The use of peat-charcoal for fuel must in great measure depend upon the cost of its production, inclusive of the cost of the original peat, and its capability of competing in that respect with other fuel, namely, wood-charcoal, certain kinds of coal, and coke.

VII. There is no satisfactory evidence to justify the statement of Johnson, that peat-charcoal of the best quality is even superior to wood-charcoal.⁵ Tested by the quantity of water evaporated, Stöckhardt found that approximately 100 lbs. of wood-charcoal were equal to 113 lbs. of peat-charcoal.⁶

Whether it is practicable to make peat-charcoal of good quality and economically in any existing form of coke-oven remains to be decided by experience.

⁴ Chevalier, Sur la Carbonisation de la Tourbe à Crouy-sur-Ourcq; Annales des Mines, s. 2, 1829, v. 225.

⁵ Peat and its Uses, p. 157.

⁶ Bergwerksfreund, ii. 553, quoted by Kerl in his "Handbuch der metallurgischen Hüttenkunde," 1861, i. 275.

COMBUSTIBLE GASES.

In the Classification of Fuels given on p. 182, the combustible volatile products of carbonization are divided into carbonic oxide, hydrogen, and hydro-carbons. These products are generally formed together, but carbonic oxide may be obtained practically free from hydrogen and hydro-carbons by the partial combustion of charcoal or coke by atmospheric air (see p. 157 *supra*). Hydrogen and hydro-carbons cannot be obtained free from carbonic oxide by any known process of treating solid fuel, capable of commercial application.

CARBONIC OXIDE.

The gases which escape from the tops of blast-furnaces, such as are used for smelting iron, etc., contain a large proportion of carbonic oxide, which may be conveyed through pipes to a distance, and employed as fuel under steam-boilers, and for other purposes. The condition under which this gas is formed by the action of atmospheric air on carbonaceous fuel heated to bright redness has been previously explained; and this condition is necessarily present in blast-furnaces. The methods by which the gases of these furnaces, or, as they are termed, "waste-gases," are utilized on the Continent and in this country will be considered in the Author's volume on Iron and Steel.

HYDROGEN.

Hydrogen in admixture with marsh-gas, carbonic oxide, and carbonic acid—generated by passing high-pressure steam through cast-iron retorts filled with coke and heated to bright redness—has been employed in iron-smelting furnaces. This gaseous mixture was first applied, I believe, by my friend Mr. John Dawes, at the Oldbury furnaces, near Birmingham. He obtained a patent for the process, which I saw in operation at these furnaces during several years. It was, however, discontinued; but my friend Mr. William Dawes, a brother of the patentee,¹ informed me, about the year 1860, that he had then lately resumed its use in blast-furnaces in Yorkshire. The composition of this gaseous mixture has been given at p. 418 (II. in the table on this page). It requires a considerable amount of fuel to keep the retorts sufficiently hot to furnish a copious and continuous current. The carbonic acid might be easily separated by means of a lime-purifier, such as is used for purifying gas in gasworks.

HYDRO-CARBONS.

These gases, together with carbonic oxide and sometimes hydrogen, are generated when wood, lignite, or bituminous coal is employed as fuel; and, being immediately afterwards burnt, the flame in reverberatory furnaces is chiefly the product of their combustion.

¹ Mr. John Dawes has long withdrawn from the iron-trade.

GAS-FURNACES.

Furnaces are now expressly constructed for the production of combustible gases, to be applied as fuel in various metallurgical operations, and it is very important that British metallurgists should be made acquainted with their construction, as it is certain that they have been adopted with advantage in many metallurgical works. Three furnaces of this kind will be described by way of illustration.

GAS-FURNACE AT THE BERLIN MINT.

The first of these furnaces was in use in the Mint and the Royal Porcelain Manufactory at Berlin when the first edition of this volume appeared. I am indebted to Dr. H. Wedding, of that city, for the following description of it, and the drawing from which the accom-

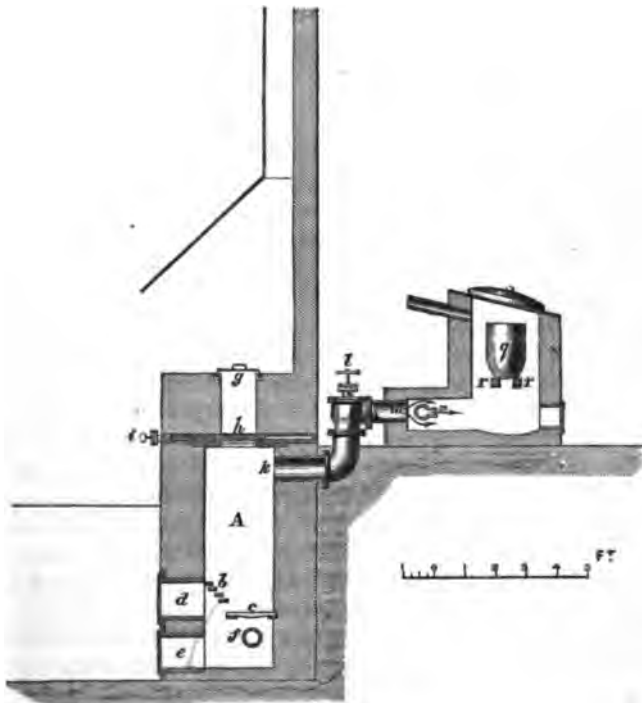


Fig. 101. Gas-furnace at the Berlin Mint. Vertical section through the centre.

panying woodcut, fig. 101, has been executed. The furnace was made in the foundry of his brother, Mr. W. Wedding, of Berlin, so that all the details may be relied upon as accurate. Brown-coal was at first employed with perfect success in this furnace, but a better result was afterwards obtained with bituminous coal, which produces

less ash. Δ is a chamber of fire-brick, having an ordinary flat grate composed of bars, c , and another grate above, in which flat bars of iron, b , are placed crosswise one above another like steps. The last kind of grate is called *Treppenrost*, or step-grate, by the Germans. The bars should be flat, horizontal, and comparatively broad. On a grate of this kind small free-burning coal may be consumed, which would in great measure drop through an ordinary grate. The distance between the bars should be such that the small coal, in dropping from one to another, may form a little *talus*, not extending beyond the outer edge of the bars. The surface of the grate, by this step-like arrangement of bars, is considerably increased, and ample space between the bars is left for the entrance of air into the furnace. The small coal of South Staffordshire might, probably, be advantageously burned on these grates. There are two openings, d and e , on a level with and below the grate respectively, which are closed by iron doors; f is an iron pipe through which a blast enters under the grate; the fuel is introduced through the opening, g , which is closed with an iron air-tight cover, as shown in the engraving. At h is a sliding iron plate, which may be drawn outwards by the handle, i . When the cavity, between g and h , is filled with fuel, the cover, g , is adjusted, and the iron plate, h , withdrawn; the fuel then drops down, and the top of the chamber, Δ , is closed again by pushing back the iron plate, h . The furnace may thus be charged from above, without allowing any direct communication with the external air. The gases generated by combustion of the fuel in the chamber, Δ , pass through the iron pipe, k , provided with a regulating valve, l , and enter the melting-furnace at m . Immediately in front of the opening, m , and extending across the furnace, is an iron pipe, n , from which atmospheric air issues through a narrow projecting piece. The combustible gases are thus brought in contact with a stratum of atmospheric air and converted into carbonic acid and water, and the flame produced proceeds onwards to the spot where a large crucible, q , is shown resting on two bearers of fire-clay, rr . The arrows indicate the direction of the currents of gas and air. The other parts of this arrangement are so clearly shown in the engraving that further description would be superfluous. In order to represent both the gas-producer and the melting-furnace in the same vertical section, it has been necessary to deviate from their actual position at the Mint, where the melting-furnace is *not behind*, but on *one side* of, the gas-producer. The atmospheric air is forced by a small fan through the pipes, f , n , which are provided with regulating valves.

EKMAN'S GAS-FURNACE.

Another of the furnaces, to be described here, was invented by Gustaf Ekman, and is in use at Ekman's Ironworks in Sweden for reheating slabs and bars of iron. In 1848 Mr. C. Ekman gave me drawings of furnaces of this kind, which, he informed me, had been in successful operation during several years previously. The wood-

cuts, figs. 102-108, on pp. 520, 521, have been executed from engravings in the *Jern-Kontoret's Annaler* for 1850, which, with the exception of some differences in minor details since introduced, have been copied by Tunner in his account of the Swedish iron manufacture published in 1858.^a In this place, only the arrangement for generating and effecting the combustion of the gas will be described; for a description of the furnace itself, the reader is referred to the Author's volume on Iron and Steel.

There is a chamber, *a*, for the production of the gaseous fuel, and which is accordingly termed the *gas-producer*, or simply the *producer*: it is built of fire-brick, and enclosed within a jacket of cast-iron, a free annular space, *ff*, being left between the two. In the fire-brick wall of the producer there are two rows of twyers, *eee*, etc., the upper one containing four and the lower one three twyers. In the iron jacket, opposite the twyers, are small corresponding holes, *ggg*, etc., fitted with movable plugs: by means of these holes the interior of the producer may be inspected. In the iron jacket is a pipe, *d*, through which cold air, at a pressure of about one inch of mercury, is injected into the space, *ff*. The blast in its passage through the space, *ff*, becomes heated to from 90° to 150° C. (Tunner); the jacket as well as the wall of the producer being thereby cooled. On the top of the producer is a hopper, *b*, through which fuel is supplied; it has a sliding bottom, *cc*, connected with a lever: near the bottom of the producer are two twyers, *e'e'*, one on each side. At *h* is an opening, fitted with a door, for the removal of ashes. The producer communicates with the body of the furnace at the fire-bridge, *m*. In the roof of the furnace is a series of openings, *ll*, etc. (shown in fig. 104 on the right of the fire-bridge), connected above with an iron box, *i*, having an easily movable lid, and communicating with the free space, *ff*, by two iron pipes, *kk*, provided with stopcocks. By this arrangement the air entering through the pipe, *d*, passes in part into the interior of the producer, and in part into the box, *i*, from which it descends through the openings, *ll*, etc. When the producer is filled with ignited fuel, and air is blown in through the pipe, *d*, carbonic oxide is copiously produced, which in its way towards the fire-bridge, *m*, is met by descending jets of heated air entering through the openings, *ll*, etc., and is thereby effectually burned. In Tunner's engravings the blast, instead of being thus divided into jets, enters the furnace as a continuous sheet of air; and the lower twyers, *e'e'*, are omitted. Wood-charcoal is the fuel employed. Mr. C. Ekman assured me that in a furnace of this description sufficient heat might be generated to melt wrought-iron by the hundredweight. The atmosphere of the body of this furnace may be made either *oxidizing* or *reducing* at will, by suitably regulating the blast passing into the producer and that descending near the fire-bridge: but it is very doubtful whether, at

^a Das Eisenhüttenwesen in Schweden, Freiberg, 1858.

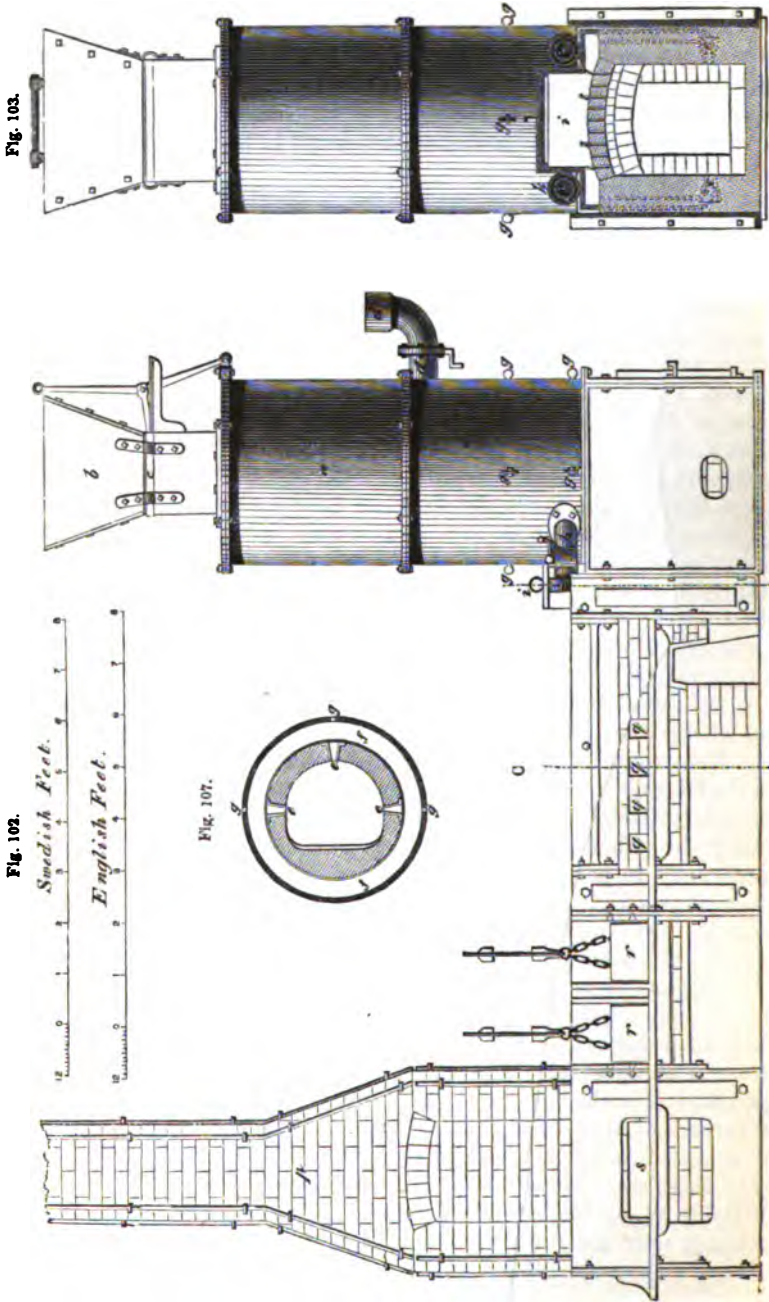


Fig. 102. Side elevation of the furnace.—**Fig. 103.** Elevation of the gas-producer on the line *x x*, **Fig. 104.** Horizontal section of the gas-producer on the line *h h*, **Fig. 104.**

D Ekman's gas-furnace.

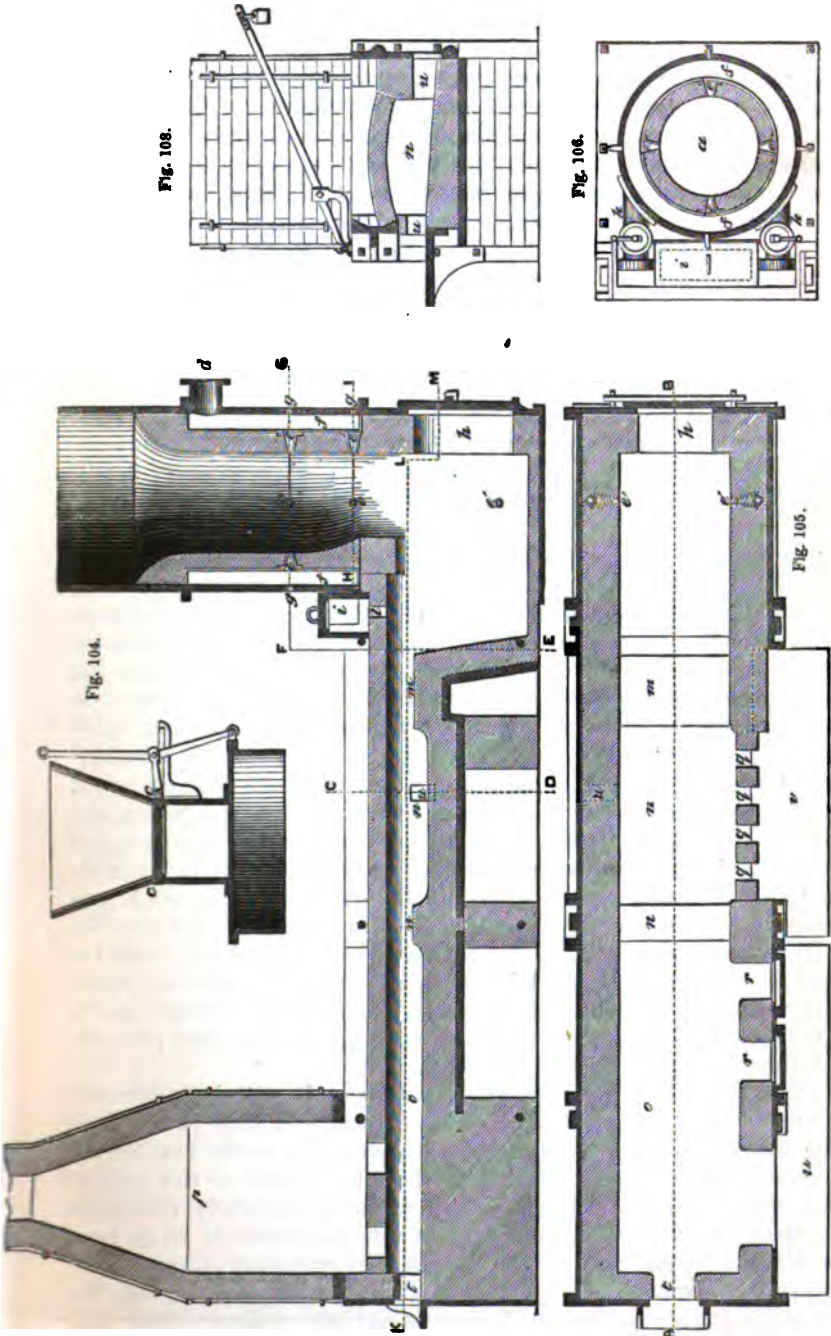


Fig. 104. Vertical section on the line A B, fig. 105. The hopper is shown separately to save space.—Fig. 106. Horizontal section on the line K L M, fig. 104.—Fig. 108. Horizontal section of the gas-producer on the line P Q, fig. 104.—Fig. 108. Vertical section on the line C D, figs. 103 and 104.

such a high temperature as is required for welding iron, the flame of a furnace can ever be rendered perfectly non-oxidizing, much less reducing. It is scarcely necessary to observe that if coal is used, it should not be of a *caking* quality. Peat artificially dried, but not charred, is extensively used in Sweden in similar furnaces. It is probable that anthracite and the slack of free-burning bituminous coal might be advantageously used in these furnaces. As anthracite burnt under these conditions would produce intense heat in the producer, where it is not wanted, and might cause rapid destruction of the brickwork, it would probably be found expedient to inject along with the air a carefully-regulated supply of steam. The temperature would be reduced by the action of the steam on the incandescent carbon, heat being consumed in the resolution of steam into carbonic oxide and hydrogen. But there would be no permanent loss of heat, because precisely the same amount of heat as is required to decompose the steam would be subsequently evolved on the combustion of the gaseous products of such decomposition in the body of the furnace.

The furnace above described was constructed for the injection of *hot* as well as *cold* air. The lower and expanded part of the chimney below *p*, fig. 102, is intended to receive apparatus for heating the air or for producing what is termed *hot-blast*. When hot-blast is used, the flame scarcely extends beyond the second bridge, *n*, so complete and rapid is the combustion of the gas. One kind of apparatus which Ekman used for the purpose of heating the blast was a zig-zag arrangement of cast-iron pipes, and another kind is represented in the accompanying woodcut, fig. 109, taken from an engraving, dated 1845, which I received from Mr. C. Ekman in 1848. It consisted of two hollow truncated cones, one smaller than, and contained within, the other; the two cones having their axes coincident, and being united at the top and bottom so as to form an annular space between the two: the apparatus was set vertically with the wide end downwards: a pipe was fixed in the outer cone near the top on one side, and another pipe was also fixed in the outer cone near the bottom on the other side; the latter pipe communicated with the iron box, *i*, fig. 104, so that air, injected into the annular space between the cones through the former pipe, would become heated, pass through the latter pipe, and burn the gas as it passed from the producer into the body of the furnace.

Both kinds of hot-blast apparatus were, it will be perceived, heated by the gaseous products of combustion as they passed from the furnace upwards through the chimney. The waste heat of the furnace was thus communicated to the air supplied to the body of the furnace, and so utilized, instead of being wastefully dissipated in the atmosphere. The principle of this utilization of waste heat is identical with that of the Siemens' regenerative furnace subsequently invented, though the particular mode of applying the principle in the last-named furnace is entirely different from and

vastly more effective than that adopted by Ekman. A notice of the introduction of methods for utilizing the waste heat of furnaces will be found in the sequel at p. 532.

As soon as I received the drawings of these gas-furnaces from Mr. C. Ekman, in 1848, I submitted them to the inspection of several iron-masters in South Staffordshire, but I could not induce any of

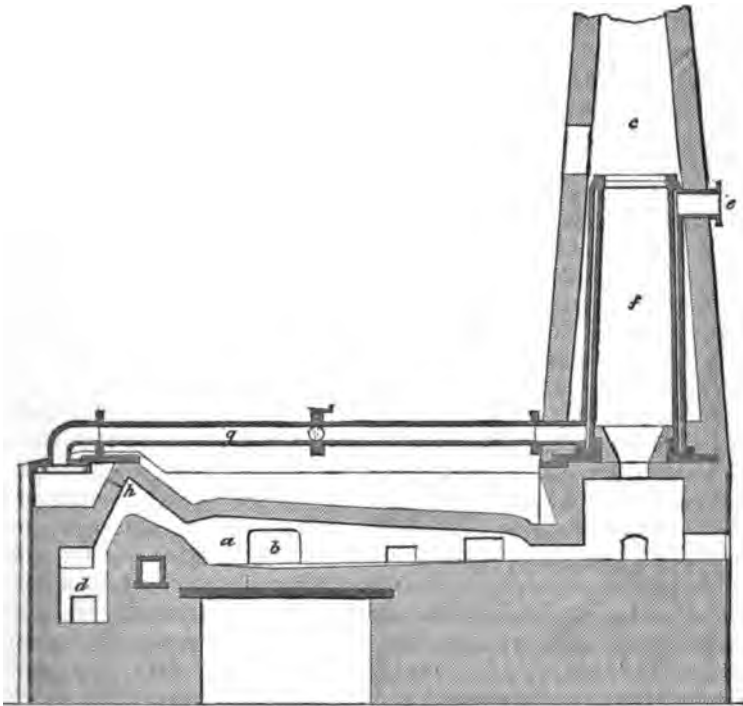


Fig. 109. Ekman's method of utilizing the waste heat of the products of combustion, by heating the blast. *a.* The body of the furnace. *b.* The working door. *c.* The chimney. *d.* A chamber through which the gaseous fuel passes, from the producer (not shown in the woodcut), in its course to the body of the furnace. *e.* A pipe, through which cold air is injected into the heating apparatus, *f.* described in the text. *g.* A pipe through which the hot-blast is conveyed to the furnace. *A.* One of a series of parallel openings, through which the hot-blast enters the furnace, and, there meeting the current of gaseous fuel, rapid combustion takes place.

them to incur the expense of building a furnace for trial; notwithstanding that the furnace appeared to offer a solution of the important practical question of a means of utilizing the small free-burning coal-slack, of which enormous quantities continue to be wasted in the collieries of South Staffordshire, South Wales, and other districts.

SIEMENS' REGENERATIVE GAS-FURNACE.¹

The principle of these furnaces is the transfer of the waste heat of the products of combustion to the air and combustible gases before entering the furnace. This is effected by means of "regenerators,"² each of which consists of a brick chamber, filled with loosely piled fire-bricks, which expose a large surface for the absorption of heat. The products of combustion on leaving the furnace are made to pass through this brickwork, and thus, on their way to the chimney, they become deprived of the greater part of their heat. After a while the direction of the currents is reversed by means of valves suitably arranged, so that now the combustible gases and air before entering the furnace pass separately through the heated regenerators in the opposite direction, coming in contact first with the cooler portions of the brickwork and acquiring successive additions of heat till they issue at a very high temperature into the furnace, where combustion is effected. At the same time the products of combustion on leaving the furnace pass down through other regenerators, previously cooled by the passage of the cold air and gases through them, and reheat these in turn: and so the process is continued, the valves being reversed at intervals of from half an hour to one hour.

In Siemens' earlier furnaces solid fuel was employed, and only the air required for combustion was thus heated by the regenerators. In one form of these early regenerative furnaces there is a single fireplace, containing a ridge of fuel fed from the top, and two chambers, in which the substance to be heated is placed, with a regenerator at the end of each chamber, whereby the waste heat passing off to the chimney is intercepted; and on reversing the draught by a valve, the air entering the furnace is made to pass through the heated regenerator in the opposite direction, and, issuing at a very high temperature into the first chamber of the furnace, it traverses the ridge of fuel and produces a flame which fills the second heating chamber, whence the products of combustion, passing through the second regenerator, deposit their heat successively in the inverse manner, reaching the chimney comparatively cool. By thus alternating the current through the two regenerators, a high temperature is maintained constantly in the furnace. This arrangement of furnace is evidently applicable only in exceptional cases, where two chambers are to be heated alternately, and it does not admit of being carried out on a large scale.

In attempting to apply the principle to heating a single chamber, as in puddling and other larger furnaces, serious practical difficulties arose, which for some time frustrated all efforts, until, by adopting the plan of converting the solid into gaseous fuel in the first instance,

¹ Various patents have been granted to Mr. C. W. Siemens and his brother, Mr. Frederick Siemens, in connection with this furnace, and a notice of them

will be found at p. 533.

² A better and more correct term, as stated on p. 456 *supra*, would be "accumulators."

and employing it entirely in the form of gas for heating purposes, practical results were at length attained.

When a uniform and sufficient supply of combustible gas is ensured, it can obviously be heated in the same manner as the air, by being passed through a separate regenerator before reaching the furnace whereby its heating power is greatly increased. The difficulty of maintaining a uniform flame in the furnace is by that means completely removed, and there is no longer any necessity for causing the flame always to pass through the furnace in the same direction, since the gas can be introduced, with equal facility, at each end of the heating chamber in turn, while the periodical change of direction of the flame through the furnace tends to make the temperature more equal throughout: whereas in the former plan, when solid fuel was used, the relative positions of the fireplace and heating chamber being fixed and unchangeable, it was necessary that the direction of the flame should be always the same, *i.e.* unaltered by the reversal of the currents through the regenerators. This plan of a separate gas-producer has now been successfully carried into practice in this country, in America, and on the Continent. It is in use at gas-works and at glassworks, and has been applied to enamelling; it is employed in the extraction of zinc from its ores, in the puddling of iron, and in the melting and reheating of steel and of various other metals and alloys.

The gas-producers are entirely separate from the furnaces, and are made sufficient in number and capacity to supply several furnaces from a common source. The fuel may be the poorest kind of slack,³ small coke, lignite, peat, wood, or even sawdust. Each producer is capable of converting from one to three tons of fuel, according to its nature and quality, daily into gas.

DESCRIPTION OF GAS-PRODUCER.—The gas-producer consists essentially of a fire-grate, on which a thick layer of fuel is maintained, so that the combustible part of the fuel is converted mainly into carbonic oxide, hydrogen, and hydro-carbons, which are carried forward through suitably arranged flues to the furnaces where they are burnt.

The gas-producers are constructed, partly of fire-bricks and partly of ordinary bricks, preferably in blocks of four each, and are built below the surface of the ground, so that the roofs of the producers are on a level with the surface.

A block of four gas-producers is shown in vertical sections, longitudinal and transverse, in Plate I,⁴ which the following description of the reference letters will explain:—

³ By using a blast under the grate, as subsequently explained, Mr. O. W. Siemens informs me that very small coal, so impure as to approach to bituminous shale in character, may be utilized.

⁴ I am indebted to my friend Mr. O. W. Siemens for the drawings from which the accompanying lithographs are taken, and for much of the information upon which this description is founded.

- a a.* Covered hoppers for charging the grate with fuel: they should always be kept filled: the covers prevent the escape of gas from the producers during charging.
- b b.* Weighted levers attached to flaps which form the bottoms of the hoppers.
- c c.* Inclined planes, made of cast-iron plates covered with fire-bricks, upon which the fuel falls, and along which it descends: the inclination of the planes and the arrangement of the grates and fire-bars are varied, according to the nature of the fuel used; that shown in the 'section at *AB*' and in the 'section at *EF*' is intended for caking, and that in the 'section at *CD*' and in the 'section at *GH*' for non-caking coal.
- d d.* Horizontal flat bars laid in steps so as to form a grate.
- e e.* The fire-bars.
- f.* A pipe for supplying water to the space below the fire-bars, where it evaporates; the steam thus produced passes through the fuel in admixture with air, which in this case has free access to the space below the fire-bars. When water is used in this manner in working two producers which face one another, the water may be conveyed from one producer to the other by means of a channel, *u*, communicating between the two.
- g.* A steam-blast which may be used instead of the water supplied by the pipe, *f*: by means of the blast a mixture of steam and air is blown into the producer.
- h.* A hole in the side of the producer through which the steam-blast enters it.
- i i.* Shutters at the back of the grate, which is enclosed, when the steam-blast is used, to prevent the escape of the blast.
- k k.* Holes in the arched roof of the producers, fitted with covers and small stoppers, for testing the gas by allowing it to escape and lighting it, and for admitting iron bars to loosen the fuel and detach clinker.
- l l.* Flues through which the gas passes off from the separate producers.
- m.* The uptake, constructed of second quality fire-bricks braced with iron rods, into which the separate flues from the four producers open.
- n.* The cooling tube of wrought-iron, 20 feet or more in length, and falling 6 inches from the uptake end to permit of any condensed liquids running off at the lower end.
- o.* The downtake, also of wrought-iron, opening into the 'main gas-flue to furnaces.'
- p.* The tar well.
- r.* A damper for cutting off the block of four producers from the main gas-flue.
- s s.* Dampers at the top of the flues, *l l*, for isolating each separate producer.

11. Doors, which are kept closed by their own weight, for obtaining access to the uptake and cooling tube when required for cleaning.

The mixture of gases on leaving the producers has a temperature varying between 300° and 430° C., and this initial heat is made available for producing a *plenum* of pressure. The heated gases are made to rise about 20 feet through the uptake, *m*, and are then cooled in the wrought-iron tube, *n*, to about 100° C. (whereby they gain about 50 or 60 per cent. in density), or to a still lower temperature: this gives a preponderating weight to the descending column in *o*, urging it forward to the furnace; thus, too, an excess of pressure (of from one- to two-tenths of an inch of water) over that of the atmosphere is maintained in the main gas-flue, whereby indraughts of air are prevented, which would tend to produce explosive mixtures in the flues. The cooling of the gases is not a waste of heat, as there is no gain in sending them hot to the regenerators; for at whatever temperature the gases may enter them, their final temperature just before combustion is always nearly the same as that of the hottest part of the regenerators.

Mr. W. Hackney, who has had great experience in the management of regenerative gas-furnaces, informs me that at the Landore Works some of the cooling tubes are several hundred feet long, and that the furnaces are found to work better, the greater the length of the cooling tubes; since the gases become more thoroughly cooled, and consequently a greater *plenum* of pressure is produced, and a larger proportion of the aqueous vapour which the gases contain is condensed.

An excess of pressure in the gas-flues might also be obtained by placing the producers at a lower level than the furnaces, but this is rarely practicable; moreover, unless the gases were cooled, they would pass through the reversing valves at a temperature too high for the convenient working of the valves.

The action of the gas-producer in working is as follows:—the fuel descending slowly on the solid portion, *c*, of the inclined plane, becomes heated and parts with its volatile constituents—hydrocarbons, water, ammonia, and some carbonic acid—which are the same as would be evolved in a gas-retort. There now remains from 60 to 70 per cent. of carbonaceous matter, inclusive of ash, to be utilized: this is accomplished by the slow current of air entering through the grate, *d*, which produces a regular combustion immediately upon the grate. The carbonic acid formed passing through a layer of incandescent fuel takes up another equivalent of carbon, forming carbonic oxide, which passes off to the furnace. For every cubic foot of combustible carbonic oxide thus produced, 2 cubic feet of incombustible nitrogen pass also through the grate, tending greatly to diminish the heating power of the gas. But not all the carbonaceous portion of the fuel is volatilized on such disadvantageous terms; for either the water below the fire-bars, or the steam-blast, *g*, supplies

steam, each cubic foot of which in traversing the layer of heated fuel becomes decomposed into a mixture consisting of one cubic foot of hydrogen and nearly an equal volume of carbonic oxide with a small amount of carbonic acid. Thus one cubic foot of steam yields as much inflammable gas as 5 cubic feet of air; but the one operation is dependent on the other, inasmuch as the passage of air through the fire is attended with the evolution of heat, whereas the production of inflammable gases from steam by decomposition, is attended by the consumption of heat: and further, the necessity for the maintenance of a strong red-heat, which is required to convert carbonic acid into carbonic oxide by contact with carbon, limits the quantity of steam which can be used.

Since the supply of air to the grate depends upon the withdrawal of the gases evolved from the producer, the production of gas is entirely regulated by the demand. By means of the dampers, *s*, the production of gas may be arrested completely for some hours without deranging the producer, which will begin work again as soon as the communication with the furnaces is re-established. The gas, however, is of a more uniform quality when there is a continuous demand for it; and for this reason, as well as to be able to supply an extra amount of gas to any furnace requiring it, it is best to supply several furnaces from one set of producers, and to keep the latter constantly at work.

The gases proceeding from the producers are a mixture of olefiant-gas, marsh-gas, hydrogen, carbonic oxide, tar vapour, aqueous vapour, and ammoniacal compounds; besides nitrogen, carbonic acid, sulphuretted hydrogen, and some bisulphide of carbon.

The following is the result of a series of analyses of producer gas made at St. Gobain:⁵—

COMPOSITION, PER CENT., BY VOLUME OF PRODUCER GAS FROM ST. GOBAIN.

| | |
|----------------------|-------------------|
| Hydrogen | 4 to 11 per cent. |
| Carbonic oxide | 15 „ 19 „ |
| Carbonic acid | 6 „ 7 „ |
| Nitrogen | 75 „ 63 „ |

The specific gravity of this mixture averages 0·78, that of air being 1·00; and a ton of fuel, exclusive of earthy matter, is capable of producing according to calculation about 50,000 cubic feet of gas at 15° C. By heating these gases to 1350° C. their volume would be more than quadrupled; but in reality a still larger increase ensues, in consequence of some important chemical changes effected at the same time. Olefiant-gas and tar vapour are well known to deposit carbon on being heated to redness, which carbon, according to Mr. Siemens, is immediately taken up by the carbonic acid and the

⁵ These analyses must be considered | gases proceeding from the producers be a
incomplete, if the list above given of the | correct one.

vapour of water, carbonic oxide being chiefly formed and hydrogen set free. These chemical changes are accompanied by a large absorption of heat from the regenerator, but the heat so absorbed is given out again on combustion in the furnace, so that the heating power of the fuel is enhanced beyond the increase due to elevation of temperature alone.

DESCRIPTION OF REGENERATIVE GAS REHEATING FURNACE.—As an example of the general mode of constructing the regenerative gas-furnaces, the application of the system to reheating iron and steel forgings has been selected.

The general arrangement of the furnace is as follows :—There are four regenerators, of which two, intended for the passage of air, are larger than the other two, for the passage of gas. The regenerators are placed below the reheating chamber, and are worked in pairs consisting of one larger and one smaller regenerator. Each pair communicates with one end of the reheating chamber.

In front of the furnace is a pit, which is covered over with cast-iron plates, supported at intervals by brick arches : there is a grating in the plates for the admission of air to the pit. In the pit are two sets of valves for regulating the supply and directing the flow of gas and of air, respectively, into the reheating chamber, through each pair of regenerators alternately. From the reheating chamber the products of combustion pass through and heat the pair of regenerators which, at the time, are not in use for the admission of gas and air. When this pair of regenerators has become heated by the passage of the products of combustion, the direction of the currents is reversed, and the gas and air are passed through the heated pair of regenerators and enter, at a high temperature, the reheating chamber where combustion takes place.

A gas reheating furnace is shown in vertical sections, longitudinal and transverse, in Plate II., to which the following description of the reference letters applies :—

- aa'*. Two regenerators, through each of which the air for combustion of the producer gas, and a portion of the heated products of combustion, pass alternately. They are fire-brick chambers, filled with walls of fire-bricks built cross-wise, all the bottom courses or rows being parallel to one another, with small spaces between each two courses, the second series of courses being set in a similar manner but at right angles to the first, the third at right angles to the second, and so alternately to the top : by which means a large surface is exposed for absorbing or yielding heat, from or to gases passing through the regenerator.
- bb'*. Two similar regenerators, through each of which the producer gas and the remaining portion of the products of combustion pass alternately.
- c*. The chamber for reheating the iron or steel forgings.
- dd*. Ports in the two end walls of the reheating chamber, com-

- communicating, by means of flues, with the two regenerators, *b* and *b'*.
- d' d'*. Similar ports, communicating with the two regenerators, *a* and *a'*.
- e*. A pipe in connection with a flue leading from the main gas-flue (Plate I.) to the regulating valve, *f*. There is a short branch pipe leading from this flue to the surface of the ground, with a stopper in the cover to it, for testing the gas, to ascertain that it burns steadily, before it is admitted to the regenerators; otherwise an explosion would be liable to occur, either from an explosive mixture being turned into the furnace, or from the gases admitted being too poor to burn well, and consequently going out and re-igniting with an explosion.
- f*. The valve for regulating the supply of gas to the reheating furnace.
- f'*. A similar valve for regulating the supply of air, which is admitted through a grating in the pit plates, as above mentioned.
- g*. The reversing valve for turning the current of gas into the regenerators, *b* and *b'*, alternately.
- g'*. A similar valve, for turning the current of air into the regenerators, *a* and *a'*, alternately.
- h h*. Flues leading from the valve, *g*, to the regenerators, *b* and *b'*, and *vice versa*.
- h' h'*. Flues leading from the valve, *g'*, to the regenerators, *a* and *a'*, and *vice versa*.
- k*. The chimney-flue, which is placed in communication with the regenerators, *a* and *b*, and with *a'* and *b'*, alternately: the valve, *g*, regulating the communication with *b* and *b'*, and the valve, *g'*, with *a* and *a'*.
- l*. The main flue, leading from the chimney-flues of several furnaces to the chimney.
- m*. The furnace damper, near the entrance to the chimney-flue, *k*. By means of this damper the pressure in the furnace is regulated, so as to draw the flame away from the working door when necessary. Close to the damper small buttresses, so inclined as nearly to meet at the bottom, are built against the side walls of the chimney-flue in order to contract the lower part of the flue at this point, by which means the draught through the furnace can be regulated by the damper with considerable precision.
- n*. Screw standard for raising and lowering the damper, *m*.
- o o'*. Screw standards in connection with systems of levers, shown in the 'section at G H,' for adjusting the valves, *f* and *f'*.
- p p'*. Levers for reversing the valves, *g* and *g'*. These valves should be reversed nearly but not quite at the same moment.
- rr*. Doorways, leading from the pit in front of the furnace into the separate regenerators. These doorways are filled in

with two thicknesses of brickwork, the inner one of fire-brick, and the intervening space is filled with sand to render it air-tight.

It will be seen that the air enters the reheating chamber *above* the gas; from its greater specific gravity it sinks through the latter, so that a perfect mixture is formed and complete combustion ensues. The products of combustion are stated to become reduced in temperature from 1400° C. on entering the regenerators to 150° C. on leaving them.

The flame of the furnace may be made oxidizing or neutral at will by means of the valves, f and f' , which regulate the proportion of gas and air admitted to the reheating chamber, c ; also, by means of the furnace damper, m , the balance of pressure between the reheating chamber and the external atmosphere may be varied as required: the best results, however, are obtained when there is a slight excess of pressure in the furnace above that of the external air. Thus the whole working of the furnace is completely under the control of the workman, who, by taking proper advantage of the means at his disposal, can prevent the iron from being burnt and so effect an important economy in addition to the saving in fuel. Experience has proved that 3 cwt. of small coal are required to heat a ton of steel ingots, and 6 cwt. of the same fuel to heat a ton of iron, to the forging point, or about half the consumption of an ordinary furnace doing the same amount of work.

A very high temperature can be attained in the regenerative gas-furnace, owing to its power of accumulating heat, without resorting to cutting flames or an intense draught. There are, however, two causes which limit the accumulation of heat: one is the fusibility of the materials composing the bed, sides, and roof of the furnace; the other is the attainment of the temperature, at which combustion of the fuel altogether ceases to take place, owing to the interference of dissociation. The phenomenon of dissociation has been previously referred to (see p. 173); its further consideration is beyond the scope of this work.

The great accumulative power of the regenerative gas-furnace is well shown in the furnace for the melting of steel in crucibles: by its means 24 pots, each containing 56 lbs., make 5 charges of "mild steel"* in the 24 hours with a consumption of 25 cwt. of small coal per ton of steel, including that used for the pot-annealing stoves; whereas in the old furnaces 2½ to 3 tons of coke are required to melt a ton of steel in similar crucibles.

A still greater saving of fuel has been effected with these furnaces in Mr. C. W. Siemens' process for the production of steel from pig-iron and ore in the open-hearth regenerative gas-furnace. In this process 6 tons of pig metal are completely decarburized by ore, and after the addition of ferro-manganese or *spiegeleisen* the charge is

* This term is applied to steel approaching to wrought-iron in composition.

run into ingot-moulds. A ton of mild steel is thus produced with a consumption of 14 cwt. of coal. This great economy is mainly due to the power of accumulating heat possessed by these furnaces.⁷

HISTORICAL NOTICE OF THE INTRODUCTION OF METHODS FOR UTILIZING THE WASTE HEAT OF FURNACES.

The utilization of the waste heat, which is carried away from furnaces by the products of combustion, is a subject which has for a long period engaged the attention of metallurgists and engineers.

As far back as 1788 a patent⁸ was obtained by Robert Gardiner, of the City of London, ironmaster, in which it was, amongst other things, proposed to apply the waste heat of furnaces to raising steam, by passing the heated products of combustion under a boiler.

The earliest description, I have met with, of a method for utilizing the waste heat, in such a manner that it is returned to the furnace itself, and the expenditure of fuel therein consequently economised, is contained in the specification of a patent⁹ which was

⁷ A description of this process, which has been carried out on a large scale at the works of the Landore Siemens' Steel Company, near Swansea, is contained in a paper read by Mr. Siemens before the Chemical Society of London in March 1873.

Mr. Siemens has favoured me with the following information regarding the application of the regenerative gas-furnaces to the manufacture of glass:—"In the manufacture of glass a very notable saving of fuel has been effected.

"The first glass-pot regenerative gas-furnace was erected by Messrs. Lloyd and Summerfield at Birmingham in 1861; and at the meeting of the Institute of Mechanical Engineers at Birmingham in 1862, Dr. Lloyd stated that the average expenditure of fuel in the year was 35 tons per week in the old furnaces, and 16 to 17 tons in the new: this furnace, which is used for making flint-glass, is still in satisfactory operation.

"For some time past Messrs. Siemens have directed their attention to the melting of glass in open tanks, so as to dispense with the use of glass-pots entirely; these proving a success at the works of Messrs. Powell, Bristol, and elsewhere, the next step was to render the process of glass manufacture continuous, so as to save the time wasted in melting the materials. These improvements culminated in the 'continuous-working tank furnace.' This furnace consists of an oblong basin, with

an arched roof, and is divided into two unequal compartments which freely communicate below a bridge; at the end of the larger compartment is the charging door, and along its sides are the gas and air ports of the regenerators; the combustion of the heated air and gas taking place here, a zone of intense heat is formed, in which complete fusion takes place, the molten glass flows under the bridge to the smaller compartment, or 'working end,' where are placed the doors through which the workmen gather the glass for blowing: thus the materials are continuously charged in at one end whilst the glass is being constantly removed from the other.

"The results obtained by the above-mentioned furnaces are exceedingly important. At Aniche, in the north of France, an 8-pot regenerative gas-furnace consumes 2½ kilogrammes of coal per kilogramme of manufactured glass. Several of the continuous-working tank furnaces are in operation at Mr. Frederick Siemens' glassworks at Dresden, where the details of the arrangements have been chiefly worked out. At Decize, in Belgium, a continuous-working tank furnace requires only 1½ kilogramme of coal per kilogramme of finished window glass, whereas an ordinary Belgian coal furnace consumes 4½ kilogrammes of coal in doing the same amount of work."

⁸ Specification, A.D. 1788. No. 1642.

⁹ Specification, A.D. 1831. No. 6103.

granted in 1831 to James Slater. The heated products of combustion are to be split up into a number of currents and conveyed through a series of long passages, made of thin iron plate and disposed in parallel courses, with intervals between each two passages; which intervals themselves form passages for the conveyance of currents of air to maintain combustion of the fuel. "One set of passages being regularly interspaced between the other set of passages, in order that the currents of smoke [i.e. the heated products of combustion] and of air may be both subdivided into small streams, and that those small streams may be so interposed one amongst the other as will (without allowing of any actual intermixture of the smoke with the air) cause the redundant heat of the smoke to pass through the thin iron plate whereof the passages are composed (and whereby the smoke is kept from actually mixing with the air), so as to cool the smoke which is passing through the smoke-passages, and give warmth or heat to the air which is passing through the air-passages; and the said cooling of the smoke and heating of the air is rendered very complete by causing the currents of air to move along the air-passages in a contrary direction to that in which the currents of smoke move along the smoke-passages." A fan is employed to produce the requisite draught through the fire; since there is no chimney-draught, owing to the products of combustion being cooled in the smoke-passages. The arrangement for utilizing the heat contained in the products of combustion, is stated in the specification to be on the same system as the French air-stoves, for warming houses. It is an ingenious application of the very principle to which, in great measure, the modern regenerative gas-furnace owes its success.

In the *Jern-Kontoret's Annaler* for 1834, there is a drawing of an apparatus, for heating the blast, placed close to the top of a blast-furnace; the hot gases escaping from the furnace are drawn off just below the top, and are introduced into the apparatus, through which the blast is conducted on its way to the furnace, whereby it becomes heated.

In the *Jern-Kontoret's Annaler* for 1843, p. 339, there is a description, accompanied by illustrative engravings, of the application, by G. Ekman, of the waste heat of his gas-furnace, to the heating of the blast used in the furnace. The description is contained in two reports, addressed to the *Jern-Kontor* (Board of Ironmasters), by L. Rinman and G. Ekman respectively. The apparatus used for heating the blast was similar to that shown in the woodcut, fig. 109, on p. 523 *supra*, which is taken from an engraving, bearing the date 1845, which I received from C. Ekman in 1848. The working of the furnace is reported to have been satisfactory.

PATENTS RELATING TO SIEMENS' REGENERATIVE GAS-FURNACE.—The following patents relating to the regenerative gas-furnace were obtained by Messrs. Siemens previously to the year 1865. The patents which they have since taken out, in reference to the application of the furnace to various purposes, are too numerous to be mentioned here:—

(1) A.D. 1856, Dec. 2nd, No. 2861. Patent granted to Frederick Siemens for "Improved arrangement of Furnaces, which improvements are applicable in all cases where great heat is required." The invention is stated to consist "in certain arrangements of furnaces, which have for their object to recover the heat which is still contained in the flame or products of combustion on passing away from the fire-place, or heated chambers, or flues towards the chimney, by causing that heat or a great portion thereof to be imparted to the current or currents of atmospheric air, gas, or other materials employed to maintain combustion in the same or other fire-places, by which arrangements heat may be accumulated to an unlimited extent (consistent with the materials employed), and great economy of fuel is effected." The specification contains, *inter alia*, the following claims:—"3rdly. Arranging two chambers containing materials presenting extensive surfaces in connection with one furnace containing one or more fire-places, in such manner that while the materials contained in one chamber are being heated by the current or currents containing the products of combustion, the heated materials in the second chamber impart heat to the current or currents of air or other gases intended to maintain combustion, and *vice versa*, the heating and heated currents being passed alternately through each of the chambers in opposite directions" (by means of suitable valves). "5thly. Arranging two or more pairs or sets of chambers containing refractory materials, and which I have termed 'regenerators,' in relation to one furnace and one or more fire-places, in such manner, that, while one pair of regenerators serves to transfer the heat of one heated current to a current of fresh air supporting combustion, a second pair of regenerators may be employed to impart heat to the carburetted hydrogen, carbonic oxide, or other gaseous material intended to enter into combination with the heated air produced by the first-mentioned pair of regenerators."

(2) A.D. 1857, May 11th, No. 1320. Patent granted to Charles William Siemens for "Improvements in Furnaces, and in the application of heated currents." The specification contains, *inter alia*, the following claim:—"Sixth, producing intensely heated flame by mixing a current or currents of heated air proceeding from a regenerator with the heated gases produced by the partial combustion or distillation of coal, effected by the admission (either alone or mixed with steam) of a quantity of air insufficient to produce perfect combustion, as hereinbefore described; also, the mode of varying the chemical nature of such flame by means of dampers or valves regulating the supply of air and gases, as hereinbefore described."

(3) A.D. 1861, Jan. 22nd, No. 167. Patent granted to Charles William and Frederick Siemens for "Improvements in Furnaces." The specification states that "it is an essential part of our invention that the solid fuel used, such as coal, lignite, peat, etc., should be decomposed in a separate apparatus, so that the introduction of solid fuel into the furnace may be altogether avoided, and the gaseous fuel

may be heated to a high degree prior to its entering into combustion with atmospheric air, also heated to a high degree, thus causing a great economy of fuel." The gas-producers, or gas-generators described in the specification, are in the main similar to those described in this volume (see p. 525 *supra*). The combustible gases ascend from the producers, and are carried forwards to the regenerators through a horizontal pipe some distance above the ground, whereby the gases are cooled and a *plenum* of pressure is maintained, so as to prevent indraughts of air, and consequent partial combustion of the gases. The regenerators are situated below the bed of the furnace.

A disclaimer of certain portions of the specification of the last patent was filed on the 25th April, 1870; but it only relates to "a certain construction of furnace or kiln for firing or burning bricks, pottery, and other articles."

(4) A.D. 1863, April 18th, No. 972. Patent granted to Charles William and Frederick Siemens for "Improvements in Furnaces which are principally applicable to the smelting of iron." The specification contains a description of the regenerative gas- and breeze-oven previously described (see p. 456), and also proposals for utilizing the combustible gases which leave the breeze-oven, by introducing them into blast-furnaces to assist the reduction of the ore, and by employing them in various other ways.

(5) A.D. 1864, Dec. 3rd, No. 3018. Patent granted to Charles William Siemens for "Improvements in Apparatus for the production, purification, and combustion of gases for heating purposes." In the specification new modifications of the gas-producer are described; also a method of heating air or gas, at intervals, by means of a single regenerator, which is reheated during the intermediate periods of time by the combustion of gas within it; also a method of purifying gases from dust by passing them at a considerable velocity into a chamber, where their motion is checked and its direction changed by their being drawn out through openings near the top of the chamber, whilst the dust, owing to its superior momentum, proceeds onwards in its original direction; steam jets may be used to assist the separation of the dust.

From what precedes, it will be seen that while we are indebted to Messrs. Siemens for by far the most successful and economical method of applying waste heat, yet that we should be unjust to their predecessors if we omitted to give them the credit of having clearly apprehended the fact that great economy would result from the utilization of the waste heat, and also of having devised ingenious methods for effecting such utilization. Messrs. Siemens' is the most highly organized result in the process of regenerative-furnace evolution.

CONCLUDING OBSERVATIONS ON FUEL.

The consideration of one or two questions of practical importance in connection with the subject of Fuel has been reserved for this place, as it was thought that they could be more usefully discussed when the other branches of the subject had been considered.

DETERMINATION OF THE CALORIFIC POWER OF DIFFERENT KINDS OF FUEL.

The calorific power of carbon, carbonic oxide, hydrogen, marsh-gas, and olefiant-gas has been stated in the article on the Calorific Power of Fuel, and the composition of the chief kinds of fuel has been subsequently given in detail; the application of the knowledge thus obtained, to the determination of the calorific power of the kinds of fuel in actual use, now remains to be considered.

The most obvious basis from which to calculate the calorific power of any fuel, the combustible part of which consisted of variable proportions of carbon and hydrogen, was the assumption that its calorific power would be equal to the sum of the calorific powers of the units of carbon and hydrogen respectively which it contained. We have seen (see p. 164 *supra*) that the theoretical result, given by this method of computation, nearly agrees with that obtained by experiment in the case of olefiant-gas, but differs considerably from it in the case of marsh-gas.

In the case of fuel containing carbon and hydrogen combined with oxygen, it was conceived that the oxygen was *virtually* in combination with hydrogen, and that only the excess of that element beyond the quantity required to form water with the oxygen present, or the *disposable* hydrogen, was available as a source of heat.

These propositions have until very recently been generally accepted as correct, and, in the absence of any certain *data* by which to be guided, they have been followed in this volume. But it will be shown in the sequel, that if the recent experimental results obtained by Scheurer-Kestner and Meunier in regard to the calorific powers of different varieties of coal are trustworthy, the preceding *data* can no longer be accurately relied on: the results which they give, however, sufficiently approximate to the truth to be of considerable value for practical purposes.

Upon theoretical grounds the sufficiency of the above *data* might fairly be questioned. The proximate constitution of coal is wholly unknown; we are ignorant whether force is liberated or absorbed during the decomposition—previously to, or at the moment of combustion—of the various compounds of carbon, hydrogen, and oxygen, of which the organic part of coal must be composed. Again the hydrogen and oxygen are present in the solid state, and we are unable to determine what amount of force may be absorbed during their conversion into the gaseous state.

The experimental results obtained by Rumford and Hassenfratz, and by Scheurer-Kestner and Mennier, relating to this subject, will now be considered; after which, a description will be given of Thompson's calorimeter, by the aid of which the relative evaporative powers of different fuels are believed to be approximately ascertainable.

RUMFORD AND HASSENFRATZ'S EXPERIMENTS ON THE CALORIFIC POWER OF WOOD.¹

Rumford and Hassenfratz many years ago experimentally determined the calorific powers of various kinds of wood by means of the ice calorimeter, in which the number of units of heat evolved by the combustion of a substance is deduced from the quantity of ice melted.

The results of these observers were as follow:—

| | Calorific Power of perfectly dry Wood, determined by Experiment. |
|-------------------|--|
| Rumford | 3654 |
| Hassenfratz | 3675 |

To compare these results with the theoretical ones calculated in the manner above described, we may take the mean ultimate composition of dry wood as deduced from Chevandier's analyses (see p. 184 *supra*); it is as follows:—

| | | In round Numbers. |
|----------------------------|--------------|----------------------|
| Carbon | 50.32 | 50 |
| Hydrogen | 6.13 | 6 |
| Oxygen | 40.73 | 41 |
| Nitrogen and ash) | 2.82 | 3 |
| | <hr/> 100.00 | <hr/> 100 |

Whence the number of units of heat theoretically producible by the perfect combustion of 1 part by weight of dry wood will be as follows:—

| | Units per cent. of the dry Wood. | | Units of Heat. |
|---|-------------------------------------|------------------------------|-------------------|
| Carbon..... | 50 will yield | $\frac{50}{100} \times 8080$ | = 4040 |
| Disposable hydrogen, $6 - \frac{41}{8} = 1$ | .. | $\frac{1}{100} \times 34462$ | = 345 |
| Total..... | | | <hr/> 4385 |

If the water supposed to pre-exist in the wood be regarded as existing in the solid state, it will be necessary to deduct its latent heat of fusion, namely, $\frac{(41 + 5)}{100} \times 79 = 36.3$ units of heat; which will leave $4385 - 36.3 = 4348.7$ as the theoretical calorific power of

¹ *Traité de la Chaleur*, ii. 60. By Peclet; 2nd edition, Paris, 1843.

perfectly dry wood.² This number, it will be seen, is considerably in excess of the numbers obtained experimentally by Rumford and Hassenfratz, but in the absence of information as to the precise composition of the wood upon which they experimented, the comparison is not altogether satisfactory; and, again, it should be remembered that their experiments were made at a time when the precautions required for the accurate determination of the calorific powers of different substances in the calorimeter were unknown.

SCHOURER-KESTNER AND MEUNIER'S EXPERIMENTS ON THE CALORIFIC POWER OF COAL.³

Scheurer-Kestner and Meunier have recently determined the calorific powers of different varieties of coal. For this purpose they made use of Favre and Silbermann's calorimeter, which they slightly modified in such a manner that the carbonic acid produced on combustion was cooled with great rapidity, whereby the quantity of carbonic oxide formed was much reduced.⁴ For the sake of comparing the experimental with the theoretical values of the coals as deduced from their composition in the manner before described, they reduced their experimental results, and calculated them as though the coals had consisted wholly of the organic constituents, excluding the ash and hygroscopic water. They made corrections for the carbon, which in their experiments in the calorimeter was retained in the ash, and also for the hydrogen and carbonic oxide which escaped combustion; but they appear to have taken no account of the sulphur in the state of sulphide, which all coal contains, and which would, in greater or less degree, according to its quantity, add to the amount of heat produced in the calorimeter. The table on the following page contains a selection from the results of these observers.

From an inspection of the table it will be seen, that in every case the experimental calorific power of the coal considerably exceeded the calculated result, and that coals with nearly the same percentage composition, so far as regards their organic constituents, may differ widely in calorific power. Notwithstanding the smaller proportion of carbon in No. 5 of the table as compared with No. 6 (the amount of disposable hydrogen being practically the same in both), the observed calorific power of the former was more than 3 per cent. greater than that of the latter. Assuming, therefore, the accuracy of the experiments, it would seem to follow that the calorific power of a coal is in part dependent upon its proximate chemical constitution, as well as upon its ultimate chemical composition.

² The reader will bear in mind that the calorific power of a substance, as determined in the calorimeter, is the total number of units of heat produced by its combustion. To ascertain the *useful heating effect* of a fuel, we must deduct the quantity of heat required to raise the products of combustion and associated

nitrogen to the temperature required for any particular operation, and this will include the latent heat of the steam produced on combustion.

³ Ann. de Chim. et de Phys. s. 4, 1870, xxi. 436; s. 4, 1872, xxvi. 80.

⁴ Compare p. 162 *supra*.

TABLE SHOWING THE EXPERIMENTAL AND THEORETICAL CALORIFIC POWERS OF DIFFERENT COALS.

| No. | Locality. | Description of Coal. | Calorific power calculated on the dry Coal, free from Ash. | | Percentage Composition of the Coal, exclusive of Ash and Water. | | | Coke, per cent., calculated on the dry Coal, free from Ash. |
|-----|---------------------------------|----------------------|--|--------------|---|-----------|----------------------|---|
| | | | Experimental. | Theoretical. | Carbon. | Hydrogen. | Oxygen and Nitrogen. | |
| 1 | } Manosque, Basses-Alpes | Lignite | 6991 | 5782 | 66·31 | 4·85 | 28·84 | 46·76 |
| 2 | | Lignite | 7363 | 6533 | 70·67 | 5·44 | 23·99 | 47·55 |
| 3 | } Louisaenthal, Saarbrück | (Not stated) | 8215 | 7066 | 76·87 | 4·68 | 18·45 | 59·49 |
| 4 | | (Not stated) | 8724 | 7871 | 83·82 | 4·60 | 11·58 | 63·58 |
| 5 | } Creusot | Caking Coal | 9622 | 8384 | 88·48 | 4·41 | 7·11 | 80·42 |
| 6 | | Non-caking Coal. | 9293 | 8585 | 90·79 | 4·24 | 4·97 | 84·12 |
| 7 | | Anthracite | 9456 | 8563 | 92·36 | 3·66 | 3·98 | 88·15 |

Scheurer-Kestner and Meunier adduce a striking example of the differences in calorific power which may result from the above-mentioned cause; in the case of two coals, which closely agree in ultimate composition, but differ by as much as 500 thermal units (or more than 5 per cent.) in calorific power: the following information with regard to these coals is given by these observers:—

| | | Bonchamp Coal. | | Creusot Coal. |
|--|-------------------------|----------------|-------|---------------|
| Composition, per cent., exclusive of ash and water | Carbon | 88·38 | ..... | 88·48 |
| | Hydrogen | 4·42 | ..... | 4·41 |
| | Oxygen and Nitrogen...} | 7·20 | ..... | 7·11 |
| | | 100·00 | | 100·00 |
| Calorific power determined by experiment | | 9117 | ..... | 9622 |
| Coke, per cent., calculated on the dry coal, free from ash | | 71·58 | ..... | 80·41 |

c/ Scheurer-Kestner and Meunier endeavour to explain the difference in calorific power of these two coals by attaching a higher calorific value to the carbon which remains in the coke formed, than to that which is evolved during the process of coking. This hypothesis, however, will not explain the discrepancy in the cases of Nos. 5 and 6 of the preceding table; and in the Author's opinion a

thorough investigation by competent analysts into the proximate chemical constitution of coal, which is at present wholly unknown, is a necessary prelude to any trustworthy explanation of the differences in question.

THOMPSON'S CALORIMETER.

This instrument, which is represented in the accompanying woodcut, fig. 110, is intended to give approximately, by means of a simple experiment, the *theoretical* evaporative power of any fuel submitted

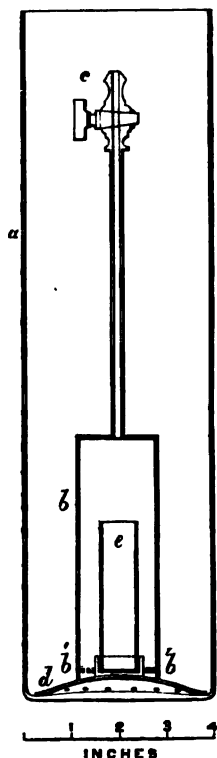


Fig. 110. Thompson's calorimeter. Vertical section through the centre.

- | | |
|---|---|
| <p>a. A glass cylinder, closed at the lower end only, to contain a given weight of water.</p> <p>b. A cylindrical copper vessel, called the <i>condenser</i>, closed at one end with a copper cover, in which is fixed a metal tube, <i>c</i>, communicating with the interior of the vessel, <i>b</i>, and fitted at its upper extremity with a stopcock. The other end of <i>b</i> is open, and it is perforated near the open end by a series of holes, <i>b'</i> <i>b'</i>.</p> | <p>d. A metal base upon which <i>b</i> is fixed by means of three springs, which are attached to <i>d</i>, and press against the internal surface of <i>b</i>, but which are omitted from the woodcut for the sake of clearness. A series of holes is arranged round the circumference of <i>d</i> to facilitate raising the apparatus through the water.</p> <p>e. A copper cylinder, called the <i>furnace</i>, closed at the lower end only, which fits into a metal ring or seat on the centre of <i>d</i>.</p> |
|---|---|

to investigation. The manner in which this result is obtained is briefly as follows:—A known weight of the fuel is burnt by means of chlorate of potash and nitre at the bottom of a vessel containing a known weight of water; the heat produced by the combustion of the

fuel is communicated to the water, and from the rise in temperature of the latter is calculated the number of parts of water which the combustion of one part of the fuel will raise one degree in temperature: this number being divided by the latent heat of steam (537 or 967 units, according as the Centigrade or Fahrenheit scale is employed), gives the evaporative power of the fuel, i.e. the number of pounds of water (supposed to pre-exist at the boiling-point) which one pound of the fuel is theoretically capable of evaporating.

In the instrument, as constructed by the manufacturer, it is intended that 30 grains of the fuel should be burnt, and that 29,010 grains (or 937 times this weight) of water should be employed; hence the rise in the temperature of the water, expressed in degrees Fahrenheit, is equal to the number of pounds of water which one pound of the fuel theoretically will evaporate: but 10 per cent. is directed to be added to this number as a correction for the quantity of heat absorbed by the apparatus itself, and consequently not expended in raising the temperature of the water.

In addition, the gaseous products of combustion generally escape from the surface of the water whilst sensibly warm. Whether this loss of heat is covered by the above correction, I am unable to state: that it is not unimportant, has been proved, in my laboratory, by enclosing the lower part of the condenser within a larger metallic cylinder, perforated all over with small holes, so that the escape of the gases from the water was retarded, when the experimental results obtained were notably higher. Thus, in comparative experiments upon a Welsh steam-coal, it was found that its theoretical evaporative power was raised from 14.41 to 14.96 lbs. of water, by enclosing the condenser in the manner described. The colder the water, the smaller will be this loss of heat; owing to the gases being more thoroughly cooled.

The experiment is conducted in the following manner:—30 grains of the finely-powdered fuel is intimately mixed with from 10 to 12 times its weight of a perfectly dry mixture of 3 parts of chlorate of potash and 1 part of nitre; the resulting mixture, which for the sake of distinction may be called the *fuel-mixture*, is introduced into the furnace, *c*, and carefully pressed or shaken down. The end of a slow fuse, about half an inch long, is next inserted in a small hole made in the top of the fuel-mixture, and is fixed there by pressing the latter around it; the furnace is then placed in its seat on the metal base, *d*, the fuse lighted, and the condenser, *b*, with its stop-cock shut, fixed over the furnace. The cylinder, *a*, is previously charged with 29,010 grains of water, the temperature of which must be recorded, and the apparatus is now quickly submerged in it. The fuse ignites the fuel-mixture, and when the combustion is finished (indicated by the cessation of the bubbles of gas, produced by the combustion, which rise through the water) the stop-cock is opened, and the water enters the condenser by the holes, *b' b'*. By moving the condenser up and down, the water is thoroughly mixed and acquires a uniform temperature, which is then recorded. By adding 10 per cent. to the

number of degrees Fahrenheit which the water has risen in temperature, the theoretical evaporative power of the coal is at once approximately determined.

The furnace shown in fig. 110 is intended to be used when bituminous coals are operated upon; but in experimenting on coke, anthracite, and other difficultly combustible fuels, a wider and shorter furnace is preferred, and the fuel-mixture should not be pressed down.

SELECTION OF FUEL FOR PARTICULAR PURPOSES.

The remarks on the Selection of Coal which will be found on p. 302, apply in great measure to other kinds of fuel. The selection must be made with reference to the particular purpose for which the fuel is required; since the manner in which fuel burns is of great practical importance, and this may depend essentially upon its physical properties. Thus, particular qualities of charcoal, coke, and anthracite may have nearly the same composition and calorific power, and yet differ remarkably in their manner of burning. Of the three, charcoal, being very light and porous, ignites most easily, and in a given volume contains the least combustible matter; and, accordingly, under the same conditions it is most quickly consumed. Coke also contains less combustible matter in a given volume, and, except when prepared at high temperatures, is more easily ignited than anthracite. The practical effect of these differences in the manner of burning will be well understood by experimenting on these three kinds of fuel in a common casting furnace about 1 foot square and from 2 to 3 feet deep. If an attempt is made to heat a large crucible in such a furnace by means of anthracite, it will be found that the bottom becomes heated to whiteness before the top is hardly red-hot; whereas by the use of coke the temperature is not so excessive at the bottom, but is much more equally diffused through the furnace. The effect of anthracite as a fuel is the rapid production of an intense heat confined to a space not extending beyond a few inches above the bars.⁵

⁵ It is obvious that on this account anthracite is not adapted as a fuel for ordinary steam-boiler furnaces; but by the following simple contrivance it may be advantageously employed in these furnaces. The ash-pit is kept filled with water, and deep fish-bellied bars are used, of which the lowest parts nearly, if they do not actually, touch the water. Steam is necessarily evolved from the surface of the water, and enters the fire-place along with the atmospheric air which sustains combustion. On passing through the incandescent anthracite, it is decomposed, with the formation of the combustible gases, carbonic oxide and hydrogen, which are afterwards burned under the boiler at a distance from the fire by the admission of a suitable supply of atmo-

spheric air from without. The decomposition of the steam causes a considerable diminution of temperature within the fire-place; but there is no permanent loss of heat, as, on the subsequent burning of the combustible gases derived from the steam, the heat absorbed in the first instance is again given out and economized: there is, so to speak, only a transference of heat from the fire-place to a distance. The bars do not become sufficiently heated to burn rapidly away. The fire-place should be enclosed above by a fire-brick arch, as no part of the boiler should be unprotected above the solid fuel. The arrangement which I have described I saw in practice many years ago at Messrs. Watney and Son's distillery at Wandsworth, and it appeared to be quite successful.

In illustration of this property of anthracite I may mention the following experiment:—At the Royal School of Mines there is a small air-furnace, 8 inches square, and 20 inches deep, connected with a chimney about 60 feet high. In this furnace, which was quite cold at the beginning of the experiment, but the chimney of which was strongly heated by adjoining furnaces, a considerable quantity of manganese was reduced and well melted by means of anthracite within 40 minutes from the lighting of the fire.

REMARKS ON THE USE OF PEAT AS A SUBSTITUTE FOR COAL.

The possibility of economically substituting peat for coal in furnaces is a subject which has recently occupied much attention, owing, chiefly, to the great increase in the price of coal which took place about two years ago. That the increase in question was mainly due to exceptional causes of a temporary character was recognized at the time, and has been sufficiently demonstrated by the reaction which subsequently set in, and which has now reduced prices to something like their former level. The tendency in the price of coal is, however, to rise; since, owing to the fact that the best, shallowest, and most workable seams are first worked out,—*ceteris paribus*—the cost of winning and raising coal will increase as time goes on. The considerations which affect the substitution of peat for coal, are therefore of growing importance; they may be divided into two classes:—

- I. Considerations relating to the suitability of peat for metallurgical purposes.
- II. Questions of cost.

I. Experience on the Continent has conclusively shown that peat-charcoal may be used in some metallurgical operations with success; also that peat may be successfully used for the production of gaseous fuel in a gas-producer. Mr. C. W. Siemens, indeed, has informed me, that, putting its cost aside, he should even prefer peat to coal for use in the producers of the regenerative gas-furnace. Now, the metallurgical operations to which gaseous fuel has been applied, are already numerous; and it seems capable of even much wider application. The drawback in the employment of peat when high temperatures are required, resulting from its containing a large quantity of water, is obviated by converting it into gaseous fuel, and subsequently condensing the moisture contained in the latter, as stated on p. 266 *antea*. So far, therefore, as the suitability of peat for metallurgical purposes is concerned, we may not unreasonably conclude, that it could be widely substituted for coal with success.

II. Questions relating to cost are much more difficult to answer satisfactorily. In this country, it is impossible, at least at present, to buy peat which will do nearly as much work as a given weight of coal, for the same money. With regard to the future, a few general

remarks must suffice. The cost of the carriage of peat is a point of great importance, since it is much more bulky, and, weight for weight, contains much less combustible matter than coal, and a large quantity of water is retained in it, even after it has been thoroughly air-dried. Not only has the cost of carriage of this water to be taken into account, but also the expense of evaporating it. The distance peat has to be carried, must therefore be as carefully considered as the labour of extraction, etc., in estimating its real cost, and its greatly inferior calorific power in estimating its value as a fuel. If desiccation by artificial means be resorted to, the cost of carriage will be diminished and the calorific value increased; but a considerable addition will at the same time be made to the cost of production.

In conclusion I may state my conviction, that peat can only compete with coal, in countries where the cost of production and carriage of peat is relatively very low, and the price of coal is relatively very high; and that, as regards Great Britain, circumstances must greatly change, before these favourable conditions for utilizing peat are fulfilled.

EVAPORATIVE POWER OF COALS.

. In regard to the evaporative power of coals, a few words may not be altogether out of place in this work. Numerous costly and very elaborate experiments have been made in this and other countries to determine the relative values of different kinds of coal with reference to steam navigation; and I have no hesitation in expressing my conviction that some of the results may lead to very erroneous conclusions. A particular boiler—it may be an old one—is selected for the purpose of experiment, and set over a particular fire-grate, etc. We will suppose two varieties of coal, say A and B, to be tested in this apparatus, and that, weight for weight, A is found to yield more steam than B; whereupon A is pronounced decidedly superior as a steam coal to B. But it is quite possible that this result may be due to the particular boiler and fire-grate being best suited to the manner in which A burns; and that under another boiler, and with another form of fire-grate, etc., B might be found superior to A. Experiments, indeed, have established that such is sometimes actually the case.

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APPENDIX.

COKE-OVENS.—(*Continued from p. 454.*)

COPPÉE'S COKE-OVEN.

THIS oven, for which a patent was obtained in England in 1868¹—though, according to Mr. Emerson Bainbridge, it had been in operation on the Continent prior to 1861²—is the invention of M. Evence Coppée, a native of Belgium. In 1873 there were in Belgium 524 of Coppée's ovens in operation, and 192 in process of construction; in Prussia, 1305 in operation and 138 in process of construction; in France, 186 in operation; and in England, 30 in operation, and 30 in process of construction.³ Bainbridge stated in 1873, that up to that time the only place in England at which this oven had been adopted was Chapeltown, near Sheffield, at the collieries of Messrs. Newton, Chambers and Co., where a batch of 30 of them had been at work for about twelve months. In 1874 two batches, each of 30 ovens, were erected at the Ebbw Vale Ironworks, and it is now proposed to construct two more batches there.

Coppée's oven is designed for coking only finely-divided coal, such as is produced by crushing coal in a disintegrator. The chief advantages claimed for it are, rapidity of coking; largely increased yield (which is considered to be the most important advantage); and better coke. It is further recommended on the following grounds; namely, that "some qualities of coal which are not sufficiently bituminous to coke in the old ovens will make good coke when burnt in the Coppée ovens;" that there is a slight saving of labour by Coppée's system; and that the waste-gases of the oven may be utilized for the raising of steam, without involving extra expense in the construction of the oven. It is also asserted that harder and denser coke may be made in this oven than can be made in the old ovens; but the truth of this assertion was certainly not exemplified in a characteristic specimen of coke which I procured from the Coppée Coke Company, Limited, London, and which, although hard and dense, did not appear to be so in a higher degree than ordinary oven-coke.

¹ A.D. 1868, July 7th, No. 2152. The title of the patent is, "Improvements in the Construction of Coke Furnaces." On August 12th, 1869, a "Disclaimer and Memorandum of Alteration" was filed.

² This statement occurs in a paper on Coppée's oven communicated by Mr. Bainbridge to the North of England

Institute of Mining and Mechanical Engineers, April 5th, 1873.

³ Notes sur quelques fours à Coke. Par M. Aug. Gillon, Professeur à l'École des Mines à Liège. *Revue Universelle des Mines, de la Métallurgie, etc.*, 1873. xxxiv. 193.

It should be added that the ovens, above referred to as "the old ovens," are those commonly known by the name of beehive ovens.⁴

The general arrangement of a batch of Coppée's ovens is shown in the woodcuts, figs. 111 and 112, on p. 547: the letters refer to the lines across which the sectional plan has been drawn.⁵ The essence of Coppée's system, as it is called, seems to me to be the rapid carbonization of coal by subjecting a comparatively thin layer of it to a high temperature in a retort-like chamber, heated on the outside by the combustion of the volatile products of such carbonization. Now, in those respects, Coppée's system resembles the Appolt system: in both the principle is the same, though the mode of applying it is different. Thus, Coppée uses a narrow long horizontal chamber for coking, and the MM. Appolt a narrow high vertical one. Moreover, Coppée's oven, both in form and in the direction of its principal axis, as well as in mode of heating, is nearly allied to other previously-invented ovens, so that it appears to be only a step in the process of coke-oven development. In support of this statement it will suffice to mention an oven long ago introduced and still used in France, at the Creuzot Ironworks;⁶ and the ovens of Smet and Dulait;⁷ all of which were narrow, and heated by the combustion of the volatile products of carbonization, mainly during their passage through horizontal flues in the sides and under the bottom; whereas in Coppée's oven the flues in the sides are vertical. But the manner of supplying air for the combustion of the volatile products from the latter oven may certainly, *à priori*, be pronounced more likely to secure the combustion of those products, without burning coal or coke to waste, than the method of supplying it in the former ovens (except in that of Appolt). Yet the volatile products are not burnt, wholly on the outside, even of Coppée's oven (according to the description in the specification of his patent), whereas they are so burnt in the case of the Appolt oven, so that the former might be regarded as theoretically inferior to the latter. It may, however, be doubted whether this objection is more than theoretical: for such part of the volatile products as is not burnt on the outside of Coppée's oven, is previously burnt by the admission of a limited quantity of air close to the top, without probably causing at the same time any combustion of the coal or coke; because the upper free surface of the coal or coke is, compared with the whole mass, only very small, and must be well protected from the air admitted by the copious current of volatile products ascending from such a mass of coal when in process of rapid carbonization.

Coppée's ovens, as previously stated, are conveniently built in batches of thirty ovens each; the ovens are worked in pairs, one oven of

⁴ The foregoing alleged advantages are those specified in a circular of the Coppée Coke Company, Limited, 94, Gracechurch Street, London, which I obtained towards the end of 1874.

⁵ The woodcuts are taken mainly, but not wholly, from Mr. Bainbridge's drawings.

⁶ See the French translation of the first edition of this volume by MM. Petitgand and A. Ronna, p. 466. Published in Paris and Liège in 1864.

⁷ See the paper by Gillon, previously referred to, in the "Revue Universelle des Mines, de la Métallurgie," etc., 1873, xxxiv. 193 *et seq.*

each pair being charged when the contents of the other are half coked, and *vice versa*. Air is admitted to the volatile products evolved from



Fig. 111.

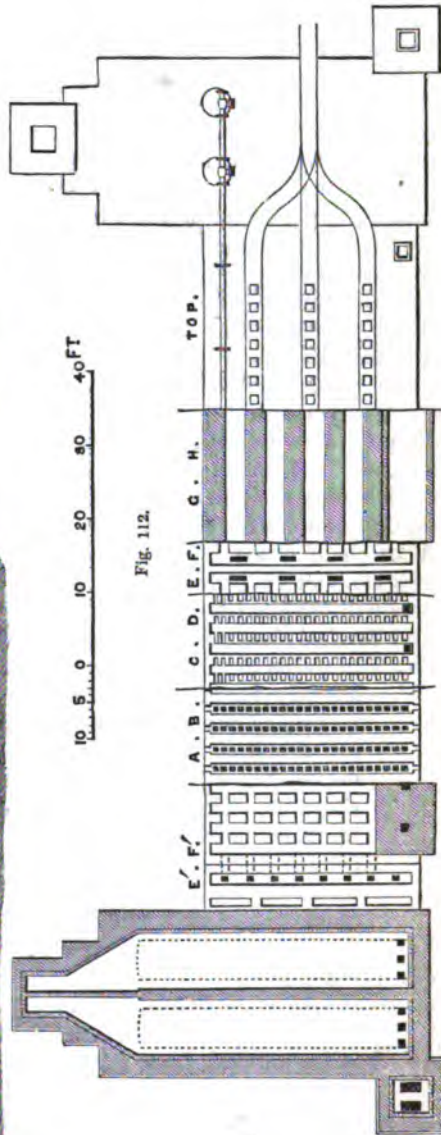


Fig. 112.

Coppée's coke-oven.

Fig. 111. Sectional elevation. Fig. 112. Sectional plan.

each oven, and then the products evolved from the two ovens forming the pair are mixed: by this means the rich hydro-carbons, which are generated at a comparatively low temperature at the commencement

of the operation of coking, are raised to a higher temperature by admixture with the more highly-heated products simultaneously evolved from the other oven of the pair, and are, it is believed, effectually burnt. The heat, resulting from the combustion of the volatile products, is communicated chiefly to the particular pair of ovens from which they have been evolved, by passing the products, to which air is admitted as above mentioned, through flues in the sides and beneath the floors of the pair of ovens in question. The coke is pushed out at the back^a of the oven by means of a ram, the construction of which will be described in the sequel.

DESCRIPTION OF COPPÉE'S OVEN. — I am indebted to Mr. E. W. Richards, the manager of the Ebbw Vale Ironworks, for full information concerning the ovens recently erected at these works from drawings supplied by the Coppée Coke Company, Limited, and for practical details of the mode of working them. Mr. Richards has, in addition, furnished me with copies of those drawings, from which Plates III., IV., V., VI., VII., VIII., and IX. have been prepared.

The ovens erected at the Ebbw Vale Ironworks do not in some respects agree with the specification of Coppée's patent. The following description has reference particularly to the ovens erected at these works, and is founded upon the information communicated to me by Mr. Richards: the chief points, in which the Ebbw Vale ovens differ from Coppée's specification, will be noticed in the sequel.

A batch of ovens is shown in vertical and horizontal sections in Plates III. and IV., which the following description and the reference letters will explain:—

a a. Vertical shoots for charging the ovens.

b b'. The ovens or coking chambers; the sides of which are built slightly tapering from back to front, to enable the coke to be pushed out at the back with greater facility. The ovens are 9 metres long, 480 millimetres wide at the back, 430 millimetres at the front, and 1·1 metre high to the crown of the arch. They are worked in pairs as above mentioned: to distinguish between the two ovens forming each pair (which is necessary, owing to the arrangement of flues under the two ovens not being precisely similar), the left-hand oven of each pair (as seen in fig. 6, Plate IV.) is marked *b*, and the right-hand oven, *b'*.

c c. Vertical flues, through which the gaseous products escape from the oven. Each oven has a series of these flues built in one of its side walls, which also forms the wall of the adjoining oven.

d d. Smaller vertical flues, through which air is admitted for the combustion of the gaseous products: each flue has a short square cast-iron pipe (fitted with a damper for regulating the supply of air) fixed into its upper end. There is one

^a For the sake of distinction, I have | and the other end, at which the ram and
termed the end of the oven, through | machinery for working it are situated,
which the coke is pushed out, the *back*, | the *front*.

- flue for each oven,⁹ through which air passes into a horizontal flue, vertically over the upper ends of each series of flues, *c c*, and communicating with the latter by short vertical flues, through which the air gains admission to the flues, *c c*.
- e e*. Horizontal flues, one of which runs under each oven marked *b*. The gaseous products from the two ovens, *b* and *b'*, forming a pair, are led into the flue, *e*, with which the two series of vertical flues, *c c*, belonging to the same pair of ovens, communicate.
- e' e'*. Horizontal flues, one of which runs under each oven marked *b'*. After the gaseous products from the pair of ovens have traversed the flue, *e*, they pass through short connecting flues, *ff*, of which there are in each case two, and return in the opposite direction through the flue, *e'*.
- g g*. Short vertical flues, one of which leads from each horizontal flue, *e*, into the main flue, *h*. This flue is only used when (repairs to the adjacent oven being requisite) it is desired that the gaseous products should not traverse the flue, *e'*. At other times the flue, *g*, is closed by a fire-brick placed over its upper end.
- g' g'*. Similar flues, one of which leads from each horizontal flue, *e'*, into the main flue, *h*. Through this flue the gaseous products from the pair of ovens ordinarily pass away. The draught is regulated by a fire-brick damper, which can be drawn more or less over the upper end of the flue, *g'*, by means of an iron bar (termed in Plate VII., a "hook for dampers"), inserted through the opening, *i*; which is at all other times closed by fire-bricks.
- h*. The main flue, which conveys away the gases from the whole of the ovens built in the batch.
- jj*. Openings, from the main flue, *h*, into the chimney.
- k*. The chimney, through which the gaseous products from the whole batch of ovens, after undergoing combustion and yielding up the greater portion of their heat, are discharged into the air.¹
- b''*. The end oven on the right of fig. 6, Plate IV. This oven has no series of vertical flues on the right side of it: in order, therefore, to heat this side, the gases, after traversing the flue, *e*, beneath the adjoining oven, *b* (with which it forms a pair), and returning in the opposite direction through the flue, *e''*, beneath the end oven, *b''*,—instead of being at once discharged into the main flue, *h*, through the vertical flue, *g''*,

⁹ The flue is in reality near the centre charging-hole of the oven, and not close to the front, as would be inferred from fig. 6, Plate IV.

¹ Although they are not shown in the Plates, yet in reality there are at Ebbw

Vale two boilers for each block of 30 ovens; and beneath these the gaseous products are conducted on their way to the chimney: the general arrangement being similar to that shown in figs. 111, 112, on p. 547 *antea*.

—are carried through cross flues, *ll*, into a horizontal flue, *m*, built on the right side of the end oven, and after traversing the latter return through another horizontal flue, *n*, (built over the flue, *m*,) and thence descend through a vertical flue, *o*, into the main flue, *k*.

pp. Open spaces above the ovens, between the vertical shoots, *aa*. These spaces are left to prevent the upper part of the structure from becoming too much heated.

q. A horizontal flue, open at one end, through which air is admitted for the purpose of cooling the foundations. There is a flue at each end of the batch of ovens, with cooling-flues in connection; but the flues connected with one end of the batch are alone shown in the Plates.

rr. Vertical flues, leading from the flue, *q*, to the horizontal flues, *ss*, beneath the ovens. The flues, *ss*, run from the side to the middle of the batch of ovens; the cool air conveyed through these flues ascends through short flues, *tt*, into the cooling-flue, *u*, and thence passes into other cooling-flues, *u'u'*; which are connected with the flue, *u*, and with each other by small cross flues, *vv*. Finally, the air passes into the flue, *w*, and thence to a small chimney, *x*. The draught in the chimney, *x*, keeps a current of air constantly circulating through the cooling-flues.

yy. The oven-doors, consisting of an upper and a lower door, which can be opened independently of one another. The doors in the front and back of each oven are alike, except in width; the difference in this respect corresponding to the difference in the width of the two ends of the oven itself, the object of which has been previously explained.

Working drawings of various fire-bricks of special form, used in the construction of the ovens, are given in Plate V. The following particulars will explain where the different bricks, shown in the Plate, are used:—

0. Ordinary 9-inch brick, put in various places.
1. Shoulder brick for cooling-flue.
2. Arch brick for ditto.
- 2*a*. Brick for levelling the work to top of arch of cooling-flue.
3. Arch brick for main flue.
- 3*a*. Ditto for forming down-take to ditto.
4. Brick for sill at front, adjoining floor of oven.
5. Brick for foundation of flue under oven-floor.
6. } Bricks for flue under oven-floor.
7. }
8. Brick for space between the floors of adjacent ovens.
9. Brick for oven-floor, and forming top of flue under oven.
10. }
- 10*a*. } Bricks for side wall of oven.
- 10*b*. }
- 10*c*. }

- 11. }
 - 11a. } Binder bricks for side wall of oven.
 - 11b. }
 - 11c. }
 - 11d. }
- 12. } Facing bricks for back of oven.
- 12a. }
- 13. } Facing bricks for front of ditto.
- 13a. }
- 14. Brick for side wall of end oven, on right of fig. 6, Plate IV.
- 14a. Brick for cover to flue at side of ditto.
- 15. }
 - 15a. } Shoulder bricks for arch over oven, leaving a space of 8 inches
 - 15b. } between each for letting the gas into side flue.
 - 15c. }
- 15d. Shoulder brick for arch over oven.
- 15e. Ditto ditto for forming charging-hole.
- 16. Arch brick, covering inlet-flue for gas to side flue.
- 16a. }
 - 16b. } Arch bricks for top of oven.
 - 16c. }
- 16d. Ditto ditto for forming charging-hole.
- 17. } Bricks covering side flue and forming air-inlet.
- 17a. }
- 17b. Brick on top of wall between oven and side flue.
- 18. Brick covering horizontal air-flue.
- 18a. Side brick for vertical air-passages, and forming floor of horizontal air-flue.
- 19. Brick forming vertical air-flue.
- 20. Brick-cover for charging-hole, fitting into cast-iron frame.
- 21. Damper, covering down-take to main flue.
- 22. } Lining bricks, for iron door at back.
- 23. }
- 24. } Ditto ditto at front.
- 25. }

Drawings of the trams, used for conveying the crushed coal to the charging-holes in the tops of the ovens, are given in Plate VI. The trams are made of wrought-iron, and their construction will be sufficiently evident from an examination of the drawings. Six trams are required for working the batch of thirty ovens; and six tram-loads, of about 10 cwt. each, constitute a charge for one oven.

A complete set of the tools used in working a batch of thirty ovens is shown in Plate VII. The numbers within parentheses indicate the number of each particular tool required for working the batch of thirty ovens. The coal-rakes are used for levelling the coal in the oven, after charging; the drags for dividing the wall of coke, as described in the sequel, after it has left the oven; the slag-

iron for detaching any clinker which may adhere to the sides of the oven; and the coke-grates for shovelling the coke into trams for removal to the furnaces.

DESCRIPTION OF THE COKE-RAM.—A ram is used for pushing the coke out of the oven. The face of it, which presses against the coke, is a little smaller than the cross sectional area of the front or narrower end of the oven, and is fixed to the end of an iron girder, somewhat longer than the oven, and having a rack on its upper surface, worked by a pinion. The whole is set upon an iron frame, together with a small engine and boiler, and the frame is mounted on wheels: rails being laid down in front of the ovens from end to end of the batch, the machine can be brought opposite to each oven in turn.

The construction of the apparatus will be understood by persons familiar with machinery, from an examination of Plates VIII. and IX. The face of the ram is constructed of two cast-iron plates bolted together, but with a small space left between them, and strongly stayed at the back. It has four small rollers, one on each side and two beneath, to facilitate its passage through the oven. The rack is of wrought-iron, 7 inches broad and $2\frac{1}{2}$ inches deep; it is bolted to a wrought-iron girder, 8 inches deep, which has a $\frac{3}{4}$ -inch plate riveted to its bottom flange. There are eight cast-iron rollers to carry the rack; and strong cast-iron side-frames, in which are the bearings of the axles of the rollers. The tail-end of the side-frames is bolted to a cast-iron carriage-box, which is mounted on two wheels, having a line of rails beneath. The other end of the side-frames is bolted to a large cast-iron frame or platform, which carries the engine for working the rack, and also the boiler. This platform rests on two wrought-iron girders, in which are the bearings of two pairs of truck-wheels, running on two lines of rails. To the axle of one pair of truck-wheels is keyed a bevil-wheel, through which the motion is transmitted, when the machine traverses the front of the ovens.

The engine has two horizontal cylinders, 8 inches in diameter, and with a 10-inch stroke: it is fitted with double eccentrics and the ordinary reversing link-motion.² From the main-shaft, which carries the cranks worked by the piston-rods, the motion is transmitted through a pair of spur-wheels to another shaft, at each end of which is a sliding clutch. The motion is communicated to the steel pinion which works the rack, by making one clutch engage with a spur-wheel, which rides loose on this shaft; and the traversing motion is obtained, by making the other clutch engage with a bevil-wheel, which also rides loose on this shaft: the motion being transmitted to the pinion and truck-wheels respectively, through other wheels in

² To avoid complication in the drawings, the link-motion in question, the steam- and exhaust-pipes, the handles for working the clutches subsequently mentioned, and various other fittings belonging to steam-engines and boilers, are not shown in the Plates.

train with those mentioned. The general arrangement of the engine is, in fact, similar to that of an ordinary travelling-crane.

There is a cylindrical boiler, 3 feet in diameter, and 7 feet high. The whole of the machinery is well under the control of one man.

MODE OF CONDUCTING THE PROCESS.—As soon as the building of the batch of ovens is completed, a small fire is lighted at each end of every oven, close to the doors. The fires are kept alight day and night, the heat being gradually raised, until at the end of four weeks the ovens are quite dry and hot: they are then fully charged with coal in small lumps. The first few batches of coke are of inferior quality; but in one week, after the ovens are first fully charged, they become so thoroughly hot, that crushed coal is used, as in the ordinary course of working the ovens, and good coke is made.

In working the ovens at Ebbw Vale, the small coal is first washed to free it from intermixed shale, and then crushed in a Carr's disintegrator.³ It is next lifted by suitable machinery into a large cast-iron bin (capable of holding about 200 tons of crushed coal), the bottom of which is sufficiently high above the tops of the ovens to allow the trams to run under it: when filled, the trams are pushed by hand along to the top of the oven for which the charge is intended; the previous charge not having yet been withdrawn. The front and back doors of the oven are now opened, and the mass of coke, 30 ft. long, 3 ft. high, and 16 in. thick, is pushed out of the oven on to the bank, by means of the ram previously described. The ram is then drawn back as quickly as possible, and the two lower doors are closed. The oven is then immediately charged through the three openings, *a a a*, fig. 1, Plate III., by drawing out the slides in the bottoms of the trams; and two men level the coal, by means of the rakes, shown in Plate VII., which are introduced through the upper doors at each end of the oven, and reach to its centre. The upper doors are then closed, and, together with the lower doors, carefully luted, to prevent access of air to the coal; carbonization immediately commences, owing to the heat of the oven, and to the circulation of the heated products from the adjacent ovens, through the contiguous flues.

The process of emptying and refilling the oven, as above described, need not occupy more than eight minutes. The coke is quenched immediately after leaving the oven: to facilitate this operation, the mass of coke, which is pushed out of the oven, is divided vertically and longitudinally into two equal parts, by means of the drags shown in Plate VII. This separation is easily effected, since carbonization takes place from the two sides towards the centre; whereby a vertical plane, similar to a plane of cleavage, is formed through the centre of

³ A description of Carr's disintegrator, in the Report of the British Association by Mr. F. J. Bramwell, will be found for 1871, part 2, p. 229.

the mass of coke. An explanation of this curious result will be found in the remarks upon Experiments on the Formation of Coke in the Appolt Oven, on p. 451 *antea*.

The ovens are numbered consecutively; the odd numbers are emptied and recharged in the morning, and the even numbers in the afternoon, six days a week. Six charges are thus coked in each oven per week; each charge yielding about two tons of coke.

The steam required for the coal-washing machine, and for the disintegrator, is generated by the waste heat of the ovens.⁴

YIELD OF COKE.—Mr. Richards informs me that at the Ebbw Vale Ironworks, 13,400 tons of coal (containing nearly 20 per cent. of shale) were sent to the washing-machine, and that 8400 tons of coke were obtained; which is equal to a yield of 62·5 per cent. on the *unwashed* coal. If the washing process be effective in removing the shale, the yield on the washed coal must be considerably greater. Mr. Richards, however, found as much as 6 per cent. of water in the coke—a point of considerable importance in estimating the yield; the large quantity of water being due to the fact that the coke is quenched outside the oven, and to the want of sufficient care in performing this operation. A series of determinations, which I have recently obtained from Bolckow, Vaughan, and Company, Limited, of Middlesborough, of the quantity of water in coke, made in beehive ovens at their New-field Collieries, and quenched inside the ovens, gave an average of only 0·8 per cent. of water.

COST OF COKING.—At Ebbw Vale the work of coking is let to a contractor, who commences by filling the trams from the bin containing the crushed coal: he finds all the labour for filling the ovens, discharging their contents (inclusive of working the coke-ram), and loading the coke into trams, for one shilling per ton of coke. The additional cost of crushing the coal in a disintegrator must be borne in mind.

CONCLUDING REMARKS ON COPPÉE'S OVEN.—The ovens erected at the Ebbw Vale Ironworks differ from the description given in the specification of Coppée's patent in the following respects. According to Coppée's specification, a portion of the air, required for the combustion of the products evolved from the coal, is to be admitted to the top of the oven itself, above the surface of the coal: whereas in the ovens erected at Ebbw Vale, no air enters the oven, the whole of it being admitted to the flues, through which the volatile products are conducted on leaving the oven. And further, in place of one main flue at Ebbw Vale, for the final exit of the gases from the whole batch of ovens, in Coppée's specification there are two; one of which contains a large boiler, intended to be heated by the waste heat of the products of combustion, which can be turned, at will, into one or other of the two main flues.

⁴ See footnote ¹ on p. 549 *antea*.

Bainbridge, in his paper upon Coppée's oven from which I have already quoted, states that "these ovens have been found by a large number of experiments to yield only 2 per cent. short of the actual quantity of fixed carbon contained in the coal." This statement might have been of some value, and would at all events have been precise, if the author of it had defined what he meant by the term "fixed carbon." He is, probably, referring to the carbon which remains in coke, when the process of coking is finished; but he seems to have overlooked the fact, that the quantity which remains, is not a fixed amount, but varies within very considerable limits with the conditions under which the coking-process takes place.

Bainbridge further states—with the convenient but unsatisfactory qualification introduced by using the word "probably"—that "a percentage, varying from 70 to 83 per cent. in Belgium, and from 67 to 75 per cent. in England, probably represents the actual results these ovens will give." Endeavouring, however, to furnish more certain and satisfactory evidence of the merits of this oven, he inserts a statement of comparative results, from which it appears that the yield is 14 per cent. higher than in the case of the beehive ovens. The amount of confidence to be placed in these results I leave to the judgment of the reader; merely remarking, that if the extra quantity of water retained in the coke from Coppée's oven, after being quenched, is included in the statement in question, the very considerable difference in the yield may not be so difficult to account for, as it would at first sight appear.⁵

It might be supposed that, owing to the thinness of the walls of this oven, frequent and expensive repairs would be necessary; but Mr. Richards asserts from his personal experience that this is not the case. Indeed, the thinness of the walls is advantageous, because the interior of the oven may, in consequence, be rapidly raised to and easily maintained at a high temperature.

It is hardly necessary to remark, that, although the coke made in Coppée's ovens is doubtless sufficiently firm to withstand the weight of the overlying mass in blast-furnaces, yet, that the large quantity of water retained in it, unless it be quenched with more than ordinary care, is a serious drawback to its use in such furnaces.

In conclusion, I think it desirable to direct special attention to

⁵ It is to be regretted that a society, such as the North of England Institute of Mining and Mechanical Engineers, should not commit the supervision of their papers to persons having a competent knowledge of the sciences which relate to the subjects treated of. As an example of the desirability of such supervision, the following passage from Mr. Bainbridge's paper may be quoted:—"The bituminous characteristic referred

to in the above classification has reference to the presence in certain coals of an intimate mingling of gases, forming a substance so far distinct as to be almost elementary, and bearing the name of bitumen."

It should be remembered that papers published by such Institutions as the one in question, are read by foreign engineers who have received a thorough scientific education.

the fact, that Coppée's oven is reported to have been largely adopted on the Continent with success, for coking and in this manner utilizing the slack of certain kinds of coal, the caking quality of which is not sufficient to enable the slack to be successfully coked in ordinary ovens: but whether Coppée's oven could be used for coking the slack of non-caking coals rich in oxygen, such as those of South Staffordshire, can only be decided by trial (see p. 309 *antea*).

REFRACTORY MATERIALS.

ORGANIC ORIGIN OF CLAY.

A very interesting discovery has been recently made by the scientific staff on board H.M.S. *Challenger*, and reported by Professor Wyville Thomson, regarding the nature of the sea-bottom in the deeper parts of the Atlantic and Southern Oceans.*

Down to depths of about 2000 fathoms the sea-bottom was found to consist of what Wyville Thomson has termed "Globigerina-ooze," containing "little else than the shells of *Globigerina*, whole, or more or less broken up, with a small proportion of the shells of *Pulvinulina* and of *Orbulina*, and the spines and tests of Radiolarians and fragments of the spicules of Sponges." From about 2000 fathoms the character of the bottom gradually changes to a "red clay," which was found almost uniformly at depths of 2500 fathoms and upwards. The change in the nature of the sea-bottom is very gradual, passing through a "grey ooze," which is intermediate in character as well as depth to the Globigerina-ooze and red clay.

The clay is stated to consist "almost entirely of a silicate of red oxide of iron and alumina," but abounding "with nodules of the peroxide of manganese," and its character over large areas was found to be very uniform; "it only varied in composition in containing more or less carbonate of lime." These considerations seemed to negative the supposition that the clay was a mechanical detritus; and the fact that many of the surface shells found in the Globigerina-ooze lived over the red clay area, and yet were not found in the clay itself, suggested that the latter was the residue left by the removal of the carbonate of lime, which formed about 98 per cent. of the Globigerina-ooze. The correctness of this view was confirmed by treating various samples of the Globigerina-ooze with weak acid, and finding that in every case a residue, of about 1 per cent., of a reddish mud was left, "consisting of silica, alumina, and the red oxide of iron," and possessing "all the characters of the red clay;" and further, small black grains of peroxide of manganese were found in the

* Proceedings of the Royal Society, 1874, xxiii. 32.

residue, "miniatures, in fact, of the larger nodules which abound in the clay."

Regarding the manner in which the carbonate of lime is dissolved, "we are not yet in a position to form any definite conclusion." Wyville Thomson states that Mr. Buchanan "believes that he finds" rather more free carbonic acid in water from great depths than in surface-water: but, if the difference is so slight that it is doubtful whether it exists at all, it can hardly assist in explaining the absence of carbonate of lime at great depths.

The deposit of clay is so uniform as regards the depth at which it occurs, and it extends over such vast areas, that Wyville Thomson "was at length able to predict the nature of the bottom from the depth of the sound, with absolute certainty, for the Atlantic and Southern sea." The removal of the carbonate of lime would therefore seem to be due to some general cause dependent upon the depth of water. Whatever the cause may be, the discovery that a red clay formation of organic origin is being very slowly deposited over areas, which cannot be estimated collectively at less than several hundred thousand square miles, is of the highest geological importance; and, as Wyville Thomson remarks, will hardly fail to throw light upon the conditions under which have been deposited certain great formations, remarkable for their red colour and the poverty of their fossil remains.

But this organic origin of red clay has already been disputed.

CUMBERLAND GRAPHITE.⁷

The following analysis of graphite from the mines of Borrowdale has been recently made in the Metallurgical Laboratory of the Royal School of Mines, by W. J. Ward:—

COMPOSITION, PER CENT., OF BORROWDALE GRAPHITE.

| | |
|--------------|--------|
| Carbon | 86.69 |
| Ash..... | 11.17 |
| Water..... | 2.14 |
| | <hr/> |
| | 100.00 |
| | <hr/> |

WOOD.

PRESENCE OF ALUMINA IN THE ASHES OF WOOD.

In the remarks appended to the table of analyses of wood-ashes, given on p. 188, special attention has been drawn to the fact of alumina having been found in the ashes; and to the difficulty of

⁷ See p. 105 *antea*.

accounting for its presence. The fact of its occurrence in some plants has, however, been established beyond all question.

Dr. A. Aderholdt, more than twenty years ago, published the following analyses of the ashes of *Lycopodium chamaecyparissus* and *Lycopodium clavatum*; in which it will be seen that alumina was largely present:⁸—

TABLE SHOWING THE AMOUNT AND COMPOSITION OF THE ASHES OF *LYCOPODIUM CHAMAECYPARISSUS* AND *LYCOPODIUM CLAVATUM*.

| Constituents per cent. | <i>Lycopodium chamaecyparissus.</i> | | <i>Lycopodium clavatum.</i> |
|--|-------------------------------------|--------------|-----------------------------|
| | Free from spores. | With spores. | |
| Alumina..... | 51·85 | 57·37 | 26·65 |
| Silica | 13·00 | 12·97 | 13·94 |
| Sulphuric acid | 4·38 | 3·24 | 4·90 |
| Phosphoric acid..... | 3·63 | 2·71 | 5·36 |
| Potash..... | 12·42 | 11·79 | 24·19 |
| Soda | 0·76 | 0·14 | — |
| Lime | 5·41 | 4·81 | 7·96 |
| Magnesia | 3·97 | 3·21 | 6·51 |
| Oxide of manganese..... | 2·20 | 2·01 | 2·53 |
| Sequoioxide of iron | 0·76 | 0·75 | 2·30 |
| Chloride of potassium ... | — | — | 2·37 |
| Chloride of sodium | 1·01 | 0·96 | 3·29 |
| Total..... | 99·99 | 99·96 | 100·00 |
| Percentage of ash in the dry plant | 6·1 | 4·5 | 4·7 |

The most recent observations upon this subject, which I have met with, are recorded in a paper by Church, entitled "Notes on the Occurrence of Aluminium in certain Cryptogams," from which I have derived the following information.⁹

The presence of aluminium is confined to a few of the cryptogams; it is not a constituent of flowering plants. Church examined different species of the following genera of cryptogams: *Lycopodium*, *Selaginella*, *Equisetum*, *Ophioglossum*, and *Psilotum*; and his results are recorded in the succeeding table:—

⁸ Annalen der Chemie und Pharmacie, 1852, lxxxii. 111 *et seq.* These analyses are also recorded at p. 136 of a work, by Dr. Emil Wolff, entitled "Aschen-Analysen von landwirthschaftlichen Produc-

ten, Fabrik-Abfällen und wildwachsenden Pflanzen," published in Berlin in 1871.

⁹ The Chemical News, 1874, xxx. 137.

TABLE SHOWING THE PERCENTAGE OF ASH, AND OF SILICA AND ALUMINA, IN CERTAIN CRYPTOGAMOUS PLANTS.

| Name of Plant. | Percentage of Ash in the Dry Plant. | Percentage of Silica and Alumina in the Ash. | |
|------------------------------------|-------------------------------------|--|----------|
| | | Silica. | Alumina. |
| <i>Lycopodium alpinum</i> | 3.68 | 10.24 | 83.50 |
| <i>Lycopodium clavatum</i> | 2.80 | 6.40 | 15.24 |
| <i>Lycopodium Selago</i> | 3.20 | 2.53 | 7.29 |
| <i>Selaginella Martensii</i> | 11.66 | 41.03 | 0.26 |
| <i>Selaginella spinulosa</i> | 3.44 | 6.67 | none |
| <i>Equisetum maximum</i> | 20.02 | 62.95 | none |
| <i>Ophioglossum vulgatum</i> ... | 8.25 | 5.32 | none |
| <i>Pellotum triquetrum</i> | 5.06 | 3.77 | trace? |

Church draws particular attention to the fact that alumina was not found in the ashes of *Selaginella spinulosa*, notwithstanding that this species is so nearly allied to some of those belonging to the genus *Lycopodium*, that it was until recently classed amongst them. He expresses his intention to examine other genera of lycopodiaceous plants, and generally to pursue his researches upon the subject. All proper care appears to have been taken to free the plants from foreign matter previously to analysis, and to avoid the introduction of alumina from the reagents and vessels used in the experiments.

Dana suggests that, as alumina has thus been found in notable quantity in certain species of *Lycopodium*; and that as lycopodiaceous plants, such as *Lepidodendron*, appear to have contributed largely to the production of coal; the inorganic matter in coal, of which alumina is a notable constituent, may have been in great measure derived from that originally existing in the coal-forming plants.¹ However this may be, it is certain that the alumina found in the ashes of coal must have been largely derived from intermixed shale; because this shale may often be seen mechanically and irregularly diffused through coal, and moreover has the same composition as the underlying clay or ground on which the coal-plants grew: and the alumina originally present in these plants would certainly be uniformly diffused through the mass of coal.

PEAT.

GEOGRAPHICAL DISTRIBUTION OF PEAT.—(Continued from p. 205.)

IN CHINA.—Peat occurs in Manchuria and Mongolia. Its occurrence in Manchuria is thus referred to in a recent work on North

¹ Manual of Geology, by J. D. Dana; 2nd edition, p. 366. New York and London, 1874.

China:—"Peat is found in great abundance along the east of the promontory [in Southern Manchuria]. We met it first at the seaport of Pi-tsze-woa, and our wonder and amusement were extreme when, two days afterwards, we found it at every inn, and huge stacks of it carefully built up in every farmyard—'peat reek' perfuming everything, and a peat bog all along the line of the great road for fully fifty miles. We saw the cuttings from which the peat was obtained, and walls of it to a great height in process of drying. The peat is black, not the brown variety."²

COMPOSITION OF PEAT.—(Continued from p. 208.)

The following analysis of artificially-prepared peat, from Loch Earn, in Perthshire, has been recently made in the Metallurgical Laboratory of the Royal School of Mines, by W. J. Ward:—

| COMPOSITION PER CENT. | | Exclusive of Sulphur, Ash, and Water. |
|---------------------------|---------------|--|
| Carbon | 65·08 | 71·43 |
| Hydrogen | 4·72 | 5·18 |
| Oxygen and nitrogen | 21·31 | 23·39 |
| Sulphur | 0·12 | — |
| Ash | 1·81 | — |
| Water | 6·96 | — |
| | <u>100·00</u> | <u>100·00</u> |

PEAT-CUTTING MACHINES.—(Continued from p. 226.)

A detailed account of Brosowsky's peat-cutting machine (shortly described on p. 225 *antea*) is given by Mr. Paget in his article on the "Utilization of Peat and Peat Lands," in the "Reports on the Vienna Universal Exhibition of 1873." The description will be found at p. 276, in Part II. of the Reports; it is illustrated by intelligible lithographs, drawn to scale. I extract the following remarks from Mr. Paget's article regarding the limits to the advantageous use of this machine:—"It is only properly applicable in rather shallow and wet moors quite free from wood and the roots of trees; being more especially of value where a thorough drainage cannot be carried out. On high bogs containing wood it cannot be used; and, in any case, beyond a depth of about nine feet, this hand apparatus is only to be worked by great exertion."

Mr. Paget has given a description, which will be found at p. 279 of the same volume, of Bocquet and Bénard's peat-excavator or *louchet*. The description is illustrated by woodcuts, and various

² Journeys in North China, Manchuria, and Eastern Mongolia; with some Account of Corea. By the Rev. Alexander Williamson. London, 1871, ii. 44. See also pp. 118, 170, and 172 of the same volume.

details relating to cost are included: the *louchet*, which resembles generally Brosowsky's machine in its mode of action, can be worked either by manual labour or by steam-power.

COMPRESSION OF PEAT.³—(Continued from p. 229.)

At p. 288 of Part II. of the "Reports on the Vienna Universal Exhibition of 1873," will be found the following remarks by Mr. Paget, upon a method, in use on the Continent, for forming peat into blocks:—"A simple process, sometimes termed in Germany and Sweden the 'Hanoverian,' is also largely employed in Holland and in Russia. The best fibrous peat is taken, and wheeled on to a hard flat surface on the field, where it is well kneaded and stamped down with the feet of men provided with wooden shoes the soles of which have been oiled or tarred. In this way the mass is gone over several times, and also beaten down by a sort of mallet, until it becomes a hard and compact cake. It is thus left for several days, when it is cut up into square blocks, and then into the smaller bricks . . . The peat worked in this way by treading is termed *Backtorf* in Austria and Germany. '*Backen*' in German, as applied to coal, means that it 'cakes' or 'packs' itself together in the fire, so that *Backtorf* may be translated as 'caked-peat.'

"In Denmark, as also in some parts of Ireland, the same operation on peat is carried out by horses' hoofs. Horses are driven round in a ring, and the trodden peat is kneaded into balls by women and children."

PROPOSAL TO GET AND PREPARE PEAT BY FLOATING MACHINERY.

(Continued from p. 251.)

Mr. Hodges' proposal to obtain peat by floating machinery has been adopted and carried into practice by the Canada Peat Fuel Company; and I have the pleasure to present the following description of the process as it is now carried out:—

"To overcome the difficulties and expense of conveying large quantities of wet peat (containing 80 per cent. of water) to a manufactory erected at a fixed place on the bog, Mr. Hodges conceived the idea of a floating machine, with the excavator and manufactory all on board. He built a scow or barge 80 feet long, about 17 feet beam, and 7 feet deep. A hole was dug in the bog large enough for the scow, into which the water filtered quickly: into this the scow was launched and fitted with her machinery, which consisted of a pair of 10 horse-power high-pressure engines, running at a speed of about 120 revolutions per minute. On one end (the bow) of the scow, a pair of large screw augers, 11 feet in diameter, are placed, working

³ See also p. 251 *antea*.

⁴ I am indebted to Mr. C. Hoffmann, formerly a student of the Royal School of Mines, and now on the staff of the Geological Survey of Canada, for ob-

taining the description of the process for me from Mr. David Aikman, the manager of the company, who has introduced some improvements in the method of drying the peat.

inside a shield or casing: these are connected with the engine by a series of cog-wheels, and are fixed on horizontal shafts $4\frac{1}{2}$ inches' diameter, fitted each with a universal joint to allow of elevation and depression to suit the depth of cut; the screws cut generally not more than 6 feet deep. On the face of the screw is fitted a knife, which projects from the outer side from the centre to the circumference, representing the cutting edge of a wood auger. The screws are so adjusted that only one is working at a time, one screw partly overlapping the other, so that, although they are 11 feet diameter, they together only cut a canal 20 feet wide. With the engine working at 120 revolutions, these screws revolve $2\frac{1}{4}$ times per minute, and at each revolution take a slice of about 2 inches: this is entirely regulated by the depth and the nature of the peat under operation. The screw in its revolution delivers the slice of peat to its rear into a well or receptacle made for it; from this it is conveyed by means of an elevator to a sufficient height to permit of its being dumped into a hopper, which delivers it into a large trough, running for about 8 feet in the same line as the elevator: this is fitted with a series of arms, which revolve or pass between other fixed arms (made at a certain curve); thus any stick or fibres are caught by the arms and thrown off into a receptacle at the side. Blades of screws are fitted at intervals between these arms, which work the peat forward to the end of this spout, where it is taken up by another similar series of arms and blades of screws placed in a smaller spout, fixed at right angles to the first and passing over the side of the scow, where, after passing a distance of about 20 feet, the open spout is converted into a tube, gradually diminishing in size, until it extends about 70 feet from the outside of the scow. The stick-catcher portion of this spout is about 6 feet long. The peat as it is forced along the spout is cut up, mashed and ground with vanes, working against flat faces of iron bars, placed across the spout. This pulping operation continues for about 6 feet more, after which the peat is reduced to a homogeneous mass in a semi-liquid state, and is passed along the spout by means of a continuous screw. Underneath the spout, at intervals of about 5 feet, are port-holes with sliding doors: these are adjusted by a man standing outside on the bog, so that the peat drops out of these holes where required, and is delivered pretty evenly over a bed previously prepared for it.

"Before commencing the season's operations with the machine, it is necessary to clear a track 20 feet wide, taking off all the moss and fibres until the surface of the solid peat is reached. This moss and stuff are generally laid alongside the track, forming a bank about 5 feet wide and 1 foot deep: this is useful as a means of passage along the side of the canal, which is cut by the machine. Outside of this bank and running parallel to the canal track, the pulp-bed is prepared; the brush or other vegetable matter growing on the bog is cut down with a short strong scythe, the moss is levelled, and any holes filled up. At intervals of every 30 feet, or according to circumstances, drains are cut across the bed: these are about 8 inches wide

and may be 10 or 12 inches deep, and are covered over roughly with boards and moss. The pulp-bed is thus prepared, about 120 feet wide.

"We may suppose the machine now at work, her screws revolving $2\frac{1}{2}$ revolutions per minute, cutting a slice 2 inches thick, thus giving a forward progress of $4\frac{1}{2}$ inches per minute, equal to $22\frac{1}{2}$ feet per hour: working 10 hours, 225 feet of canal, 20 feet wide and 6 feet deep, are cut per day. The operation of pulping, separating sticks, etc., has been going on simultaneously. The pulp which has been dropped from the long spout has been evenly spread by a couple of men with broad wooden scrapers over a track about 8 inches deep, 120 feet wide, and the same length as the machine has progressed. The drains, which have been previously prepared, now carry off speedily the water which filters away from this bed of semi-liquid peat-pulp: after lying for about 24 hours, the surface of the peat gets set, and the mass is firmer. Two men, one on each side of the bed, are then set to work to score the bed across in lines, 5 inches apart: this is done by means of a light drum of galvanized iron, about $2\frac{1}{2}$ feet long and 2 feet diameter, with a shaft passing through the centre, and armed on the outside with knives, 4 inches deep and 5 inches apart, passing round the circumference of the drum; this instrument is dragged by each man alternately to his side of the bed, and so on, following the floating machinery in its progress. As the pulp begins to dry it contracts, and, if these incisions were not made, would crack over the whole surface in irregular lines.

"After a few more days the surface of the pulp is solid enough to bear a man standing on a board. A series of boards are fastened together, forming a walk 30 feet long and $1\frac{1}{2}$ feet wide: on this two men with a circular disc-cutter pass backwards and forwards making longitudinal cuts, which penetrate to the bottom of the pulp on each side of the board walk, which is removed from side to side and advanced forward as the work progresses.

"In about a fortnight the shrinkage of the pulp in the course of drying causes the cuts made in it to open, and the whole presents the appearance of a vast floor of bricks, each 18 inches long and 5 inches wide. As soon as the bricks are sufficiently dry to handle, one or two men pass on boards across the bed with a broad spade, cutting the incisions first made with the drum quite through to the bottom of the pulp (the longitudinal cuts were made at first through to the bottom), each brick being detached from its neighbour. A gang of boys about ten in number now pick up the bricks, and within 3 feet of them behind is prepared a row of drying racks, on which the bricks are placed and remain until dry. These racks are formed by a series of what might be called short ladders, having four cross-pieces a foot apart. About 18 inches below the lowest cross-piece, the ends of the sides of these ladders are pointed, so that when put in their places they can be easily pushed down into the bog. These are stuck into the bog in a row across the bed 4 feet apart, then on the bottom cross-pieces are laid three laths, which form a shelf 18 inches wide: on this the moist bricks are laid by the boys. As soon as the bottom shelf is filled

another set of laths is put up, which in its turn is also filled up; a third is added in the same way; and a fourth, forming the top, finishes the row. Another row is set up about 4 feet in advance of the first, which in its turn is filled, and so on. The gang of ten boys and two men will cut out and rack a length of about 250 feet of the track per day.

"The bricks after lying in these racks for about a fortnight are turned over by a couple of boys, and in a few days afterwards are fit for the market. The bricks are collected from the racks by means of small cars passing between the rows on a light portable wooden track. When loaded, these are run on to a barge, which, after receiving its full complement of loaded cars (and leaving a corresponding number of empties), is hauled to the delivery staging, or the cars may be hauled by means of a light wooden track directly from the bed to the delivery staging.

"The fuel is delivered either into large sheds for storage, or loaded into railway cars and removed for consumption. One machine working at the rate already mentioned will produce about 70 tons of dry fuel per day: by experience it is found that $\frac{2}{3}$ ths of the number of feet the machine advances (when working $5\frac{1}{2}$ feet deep) will be the number of tons of dried fuel produced.

"The cost of manufacture, as described above, is about $1\frac{3}{4}$ dollars per ton, covering all expenses, superintendence, interest, insurance, etc. The selling price of the fuel at present is $3\frac{1}{2}$ dollars per gross ton.

"A new system of manufacture has lately been introduced by the Manager of the Canada Peat Fuel Company's works. He takes the peat from the elevator above described, where it is dumped into a hopper, and, instead of passing it into a spout, it is dropped on to a peculiarly-shaped web of open canvas, which revolving in a continuous circuit is formed into bags. Passing between presses all working at an unequal rate of speed, the water is pressed out, and the peat at the other end of the presses is delivered into the hopper of a pug-mill in a state of consistency something like putty. In the pug-mill it passes down between sets of knives, etc., into a horizontal spout worked with a screw and projecting beyond the side of the scow; attached to the scow at this point is a long endless web running on rollers: this passes across the bed. The mass of pulped and prepared peat as it issues from the orifice of the horizontal spout, is divided into three streams, by divisions in the orifice, and passing on to the web is carried forward. The peat is cut into lengths of 2 feet by a mechanical arrangement (a strained steel wire worked by a cam). As the bricks are carried forward on the web across the bed, boys with two pieces of wood lift them off, and deposit them on racks or trays behind them, which follow them closely up as the machine advances: here the bricks remain until dry, which is in about a fortnight."

In the article upon the "Utilization of Peat and Peat Lands," by Mr. Paget, C.E., contained in Part II. of the "Reports on the Vienna

Universal Exhibition of 1873," it is stated, at p. 338, that "the peat produced by Hodges' Canadian Peat Company at Montreal for the Grand Trunk Railway is, by Mr. Aikman, and the Railway Company, said to cost 80s. per ton;" or about five times the amount named in the preceding description of the process, which I received, in the winter of 1874, direct from Canada, as stated in the footnote on p. 561.

Now, according to Mr. Paget, coal, in 1873, cost from 5 dollars 5 cents to 7 dollars 15 cents (or from about 21 to 30 shillings) per ton, at the tide-water shipping ports of the United States; and also, according to Mr. Paget, "peat can only be sold at prices ranging from one-third to one-fourth of the local selling price of average coal." Allowing, therefore, even the most exorbitant addition, on account of freight and duties, to the cost of the coal, when delivered in Canada; it is impossible to conceive, that, if the figures given by Mr. Paget were correct, the peat produced by the Canada Peat Fuel Company could be sold at all: we may therefore infer that the price of the peat, quoted by him, is not correct.

On the other hand, it will be observed that, according to the information I have received from Canada, the selling price of the peat is exactly double the cost of its manufacture, "covering all expenses, superintendence, interest, insurance, etc."! If this statement be correct, we may congratulate the shareholders, upon the possession of one of the most successful peat-enterprises of the present day.

It should be added, that Mr. Paget quotes a statement, but without giving his authority for it, to the effect that an English company has commenced operations in the Grand Duchy of Oldenburg, upon Hodges' process of manufacturing peat.

INTERMIXTURE OF PEAT AND OTHER SUBSTANCES.

(Continued from p. 254.)

In the remarks on the patent laws, given under this head on pp. 252, 253, *antea*, it is stated that the fees paid to the law officers in connection with the granting of patents "have been commuted, and that they are to receive instead, the Attorney-General £7000, and the Solicitor-General £6000 per annum." These sums, however, considerably exceed the fees they formerly received from patentees; hence there is an apparent anomaly in the salaries being fixed so high. The explanation is this; certain other emoluments—partly of a complimentary character, granted for services which the recipients were not expected to perform—were dealt with at the same time and included in this commutation.⁵

⁵ The following extracts from a Treasury minute of the 14th Dec., 1871, explain the basis upon which the commutation was made:—"The Attorney-General shall receive £7000 a year for non-contentious business, and the Solicitor-General £6000 a year."

"The law officers shall receive fees for contentious business, and for opinions connected with it, according to the ordinary professional scale."

"All complimentary briefs and payments for services not intended to be given shall be abolished."

With these very liberal salaries, we may contrast the proposal of Lord Cairns, the present Lord Chancellor, in the bill for the amendment of the patent law, which he has this session (1875) introduced into Parliament, to appoint five additional commissioners of patents, without giving them any remuneration whatever for their services!

THE RECLAMATION OF PEAT LANDS.

This is a subject of great importance in the case of countries, such as Holland and Ireland, where peat-bogs occupy a very considerable part of the whole surface of the land. In Holland for very many years great attention has been paid to the utilization of peat lands, and I am desirous of bringing the subject before the notice of persons in this country. The following extract is taken from Mr. Paget's article on the "Utilization of Peat and Peat Lands," in Part II., p. 334, of the "Reports on the Vienna Universal Exhibition of 1873:"—

"In Holland not less than 40,000,000 tons of peat fuel⁶ are raised and dried each year; yielding in excise duty £140,000 per annum.

"It is probable that the ways in which the hard-working Dutch make use of their peat-beds would afford the most fruitful applications, at any rate as regards the reclamation of peat lands. It is perhaps not generally known or remembered that the Dutch, during the reign of William III. and Mary, offered to drain and reclaim into pasture land the whole of the great Irish bog of Allen, in Queen's county, if only allowed to be governed by their own laws. As this bog is lying waste to this day, and as an important example has thus been lost, many will regret that the offer was not accepted. Perhaps it is not even now too late. Some of the richest soils in Ireland are, however, said to be due to a mode of cultivation, very similar to the Dutch plans, introduced by emigrants popularly known in Ireland by the name of 'Palatines,' and possibly of German or Dutch descent."

COAL.

GASES OCCLUDED IN COAL.—(*Continued from p. 289.*)

Von Meyer has published in Erdmann's *Journal für praktische Chemie* for 1873, cxiv. 389, an account of some further researches, which he has made, into the nature of the gases occluded in coal. The coals of the Saarbrück basin are the subject of this memoir: but I have not found any new observations or results, sufficiently remarkable or important to induce me to insert a notice of them in this place.

⁶ It is presumed that by this expression undried peat is meant, but the point is not clear.

COMPOSITION OF VARIOUS COALS.—(*Continued from p. 349.*)

I am enabled to present the following additional information, derived from original sources, concerning the composition and character of coals, found in various parts of the world:—

LIGNITE FROM SYRIA.

COMPOSITION PER CENT.

| | | Exclusive of Sulphur, Ash, and Water. |
|---------------------------|--------------|--|
| Carbon | 58·40 | 73·39 |
| Hydrogen | 4·47 | 5·62 |
| Oxygen and nitrogen | 16·71 | 20·99 |
| Sulphur | 4·39 | — |
| Ash | 6·61 | — |
| Water | 9·42 | — |
| | <hr/> 100·00 | <hr/> 100·00 |
| Coke % | <hr/> 55·90 | |

This lignite, which I received from Mr. Larking, is found within ten miles of the coast of Syria, but of the exact locality I am ignorant. It is pitch-black on a fresh fracture, but becomes dull on long exposure. The weathered surface is in places covered with an ochreous film, probably due to the oxidation of iron-pyrites, which it contains very finely disseminated. Resin, chiefly in small particles, is diffused through portions of it. It yields a slightly lustrous, but non-coherent coke. Colour of the ash, red. The analysis was made in the Metallurgical Laboratory of the Royal School of Mines, by C. Law.

ANTHRACITE FROM PERU.

COMPOSITION PER CENT.

| | | Exclusive of Sulphur, Ash, and Water. |
|---------------------------|--------------|--|
| Carbon | 82·70 | 97·34 |
| Hydrogen | 1·41 | 1·66 |
| Oxygen and nitrogen | 0·85 | 1·00 |
| Sulphur | 10·35 | — |
| Ash | 3·75 | — |
| Water | 0·94 | — |
| | <hr/> 100·00 | <hr/> 100·00 |

This coal, which I received from Mr. H. Bauerman, an Associate of the Royal School of Mines, is found at Porton in the Pampas of the Sierra—a table-land about 13,000 feet above the sea-level, and 40 miles

north-east of Truxillo. It occurs as a bed from $6\frac{1}{2}$ to $7\frac{1}{2}$ feet thick, standing nearly in a vertical position and interstratified with quartzite. The outcrop of the bed can be followed along the base of the quartzite hills for about a mile; the country being nearly bare of vegetation. The age of this coal is probably Oolitic or Cretaceous, and that of its upheaval probably early Tertiary: the alteration being contemporaneous with the trachytic outbursts, containing the gold- and silver-bearing lodes of Salpo, which are about 20 miles nearer the coast. The sample analysed came from the upper part of the seam, and is remarkable for the very large proportion of sulphur it contains. Another sample, taken from the store at the Motil silver-reduction works, where it was used in the calcining furnaces, contained only 1.04 per cent. of sulphur. The first sample lost on heating in a covered crucible over an air-gas flame, 4.39 per cent. Colour of its ash, white. The analysis was made in the Metallurgical Laboratory of the Royal School of Mines, by W. J. Ward.

The following experiment was made upon a portion of the first sample, to ascertain the amount of sulphur retained in the coal after it had been very strongly heated:—A small clay crucible was charged with 1000 grains of the coal in small lumps, and then enclosed within a larger crucible; the space between the covers of the two crucibles being filled with coke, in order to prevent access of air to the coal, and loss by combustion during the experiment. The whole was then heated in an iron-assay furnace for about an hour, and raised to a temperature sufficient to melt wrought-iron. The loss in weight from this treatment amounted to 7.02 per cent.: and the quantity of sulphur in the ignited residue was found to be 7.35 per cent.; which is equal to 6.83 per cent. of the original coal. It thus appears that only 3.52 per cent. of sulphur was evolved on heating the coal in the manner described.

The retention of so large a quantity of sulphur in the carbonaceous residue, after it had been strongly ignited, must excite surprise, when it is borne in mind that the coal only yielded 3.75 per cent. of ash. The ash consisted principally of silicate of alumina, and only contained 0.018 per cent. of sulphur; by far the greater portion of the sulphur retained in the residue must therefore have been in organic combination. The retention of sulphur in organic combination in anthracite, after exposure to a red-heat, has been recorded by Voelcker;⁷ but, that it is not expelled at an intense white-heat, has not, I believe, been previously ascertained. The subject is deserving of further investigation; and considering the tendency of carbon and sulphur to combine on being brought into contact at a high temperature, and to produce such a highly volatile substance as bisulphide of carbon, it is probable that interesting results would be obtained.

⁷ Analysis of the Anthracite of the Calton Hill, Edinburgh; by Dr. A. Voelcker. Edinburgh New Phil. Journal, 1850, xlviii. 333.

MISCELLANEOUS TABLE OF COALS, CHIEFLY BRITISH (continued from p. 333).

| Number. | Locality. | Composition per cent.* | | | | | | Coke per cent. | Composition, per cent., exclusive of Sulphur, Ash, and Water. | | | |
|---------|---------------------------|------------------------|-----------|----------------------|----------|-------|--------|----------------|---|-----------|----------------------|--|
| | | Carbon. | Hydrogen. | Oxygen and Nitrogen. | Sulphur. | Ash. | Water. | | Carbon. | Hydrogen. | Oxygen and Nitrogen. | |
| 116 | South Wales | 91.04 | 3.20 | 1.55 | 1.06 | 1.90 | 1.25 | 94.00 | 95.04 | 3.34 | 1.62 | |
| 117 | Ditto | 86.32 | 3.08 | 4.29 | 0.66 | 4.77 | 0.87 | 85.08 | 92.12 | 3.29 | 4.59 | |
| 118 | Ditto | 86.71 | 4.71 | 3.20 | 1.53 | 3.06 | 0.79 | 80.72 | 91.63 | 4.98 | 3.39 | |
| 119 | Ditto | 83.99 | 4.42 | 2.42 | 2.60 | 5.75 | 0.73 | 81.08 | 92.45 | 4.89 | 2.66 | |
| 120 | Ditto | 84.99 | 4.39 | 3.70 | 1.49 | 4.83 | 0.60 | 80.52 | 91.30 | 4.72 | 3.98 | |
| 121 | Ditto | 88.25 | 3.71 | 2.09 | 0.84 | 4.13 | 0.98 | 92.59 | 93.83 | 3.96 | 2.22 | |
| 122 | Ditto | 83.74 | 4.83 | 3.72 | 1.01 | 6.02 | 0.68 | 78.12 | 90.74 | 5.23 | 4.03 | |
| 123 | Ditto | 84.75 | 4.82 | 4.79 | 0.84 | 4.15 | 0.65 | 75.52 | 89.81 | 5.11 | 5.08 | |
| 124 | Ditto | 84.44 | 5.00 | 4.83 | 0.81 | 4.87 | 0.65 | 74.60 | 90.15 | 5.34 | 4.51 | |
| 125 | Ditto | 83.64 | 4.64 | 5.76 | 0.75 | 4.55 | 0.66 | 73.22 | 88.95 | 4.93 | 6.12 | |
| 126 | Ditto | 90.53 | 3.61 | 1.89 | 1.07 | 1.30 | 1.60 | 91.90 | 94.27 | 3.76 | 1.97 | |
| 127 | Ditto | 85.88 | 3.51 | 2.47 | 0.80 | 5.87 | 1.49 | 91.88 | 93.48 | 3.82 | 2.70 | |
| 128 | Ditto | 75.85 | 4.74 | 7.72 | 1.09 | 8.87 | 1.73 | 69.40 | 86.01 | 5.25 | 8.74 | |
| 129 | Ditto | 74.90 | 4.98 | 8.16 | 1.69 | 8.17 | 2.10 | 65.60 | 85.06 | 5.65 | 9.27 | |
| 130 | Ditto | 85.79 | 3.71 | 2.17 | 1.89 | 5.25 | 1.19 | 91.68 | 93.58 | 4.05 | 2.37 | |
| 131 | Ditto | 86.14 | 3.40 | 2.39 | 1.83 | 4.42 | 1.82 | 91.20 | 93.71 | 3.69 | 2.60 | |
| 132 | Ditto | 89.53 | 3.66 | 1.98 | 1.38 | 1.75 | 1.70 | 91.10 | 94.07 | 3.85 | 2.08 | |
| 133 | Leicestershire | 69.00 | 4.35 | 10.78 | 0.78 | 5.42 | 9.67 | 58.14 | 83.93 | 4.62 | 11.45 | |
| 134 | South Staffordshire | 68.40 | 4.43 | 10.28 | 1.05 | 8.91 | 6.93 | 64.00 | 82.30 | 5.33 | 12.37 | |
| 135 | Ditto | 67.34 | 4.62 | 11.68 | 0.62 | 8.00 | 7.74 | 60.70 | 80.51 | 5.52 | 13.97 | |
| 136 | United States | 83.31 | 5.54 | 6.86 | 0.74 | 2.15 | 1.40 | 85.99 | 87.04 | 5.79 | 7.17 | |
| 137 | Ditto | 76.70 | 5.67 | 13.03 | .. | 4.60 | .. | .. | 80.40 | 5.94 | 13.68† | |
| 138 | Ditto | 78.80 | 4.59 | 4.88 | .. | 11.73 | .. | .. | 89.27 | 6.20 | 5.53† | |

* The composition, given under this head, of Nos. 137 and 138 is calculated on the dry coal.

† The sulphur is included with the oxygen and nitrogen in the cases of Nos. 137 and 138.

Of these analyses, Nos. 137 and 138 were made many years ago by the Author, and the remainder were made recently in the Metallurgical Laboratory of the Royal School of Mines, by W. J. Ward, with the exception of Nos. 134 and 135, which were made by C. Law.

116. Capel Ifan Colliery, Caermarthenshire. Anthracite. Colour of the ash, red.

117. Llangennech Colliery, Llanelly, Glamorganshire. Steam coal. Coke lustrous, firm, and coherent. Flame yellow, slightly smoky. Colour of the ash, pale-red.

118. Top coal, Glyn Corrwg Colliery, Glamorganshire. Coke firm, rather dull, not porous, in concentric layers. Flame yellow, rather smoky. Colour of the ash, pink.

119. Middle coal, Glyn Corrwg Colliery, Glamorganshire. Coke firm and coherent, in concentric layers. Flame yellow, smoky. Colour of the ash, red.

120. Bottom coal, Glyn Corrwg Colliery, Glamorganshire. Coke firm and coherent, in concentric layers. Flame yellow, smoky. Colour of the ash, pink.

121. Cornish vein, Pwllfaron Colliery, Glyn Neath, Glamorganshire. Anthracite. Colour of the ash, dark greyish-red.

122. Old coal or Lower Four-foot vein, Nant-y-glo and Blaina Collieries, Monmouthshire. Coke lustrous, firm, and coherent. Flame rather smoky. Colour of the ash, pale-red.

123. Top vein of Three-quarter coal, Nant-y-glo and Blaina Collieries, Monmouthshire. Coke lustrous, firm, and coherent. Flame rather smoky. Colour of the ash, reddish-grey.

124. Big vein or Upper Four-foot vein, Nant-y-glo and Blaina Collieries, Monmouthshire. Coke lustrous, firm, and coherent. Flame rather smoky. Colour of the ash, pinkish-grey.

125. Elled vein, Nant-y-glo and Blaina Collieries, Monmouthshire. Coke lustrous, firm, and coherent. Flame rather smoky. Colour of the ash, reddish-grey.

126. Green seam, Trimsaran Colliery, Caermarthenshire. Anthracite. Colour of the ash, red.

127. Grey-gog seam, Trimsaran Colliery, Caermarthenshire. Anthracite. Colour of the ash, white.

128. Top coal, Henllis Colliery, near Newport, Monmouthshire. Coke firm and coherent. Flame yellow, smoky. Colour of the ash, grey.

129. Bottom coal, Henllis Colliery, near Newport, Monmouthshire. Coke firm and coherent. Flame yellow, smoky. Colour of the ash, reddish-grey.

130. Upper or Penygraig vein, Cwm Click, Glamorganshire. Anthracite. Colour of the ash, reddish-grey.

131. Lower or Welsh vein, Cwm Click, Glamorganshire. Anthracite. Colour of the ash, pale-red.

132. Ynysgeinon Colliery, near Llanelly, Caermarthenshire. Anthracite. Colour of the ash, red.

133. Whitwick Colliery, Coalville, Leicestershire. Coke firm and compact. Flame yellow, slightly smoky. Colour of the ash, pinkish-white.

134. Sawyer Coal, Grace Mary Colliery, Rowley-Regis, South Staffordshire. This coal forms one of the constituent seams of the Ten-yard or Thick-coal; the sample analysed came from the neighbourhood of an igneous dyke. Coke slightly coherent, moderately lustrous. Flame yellow, smoky. Colour of the ash, buff.

135. Brasils Coal, Grace Mary Colliery. This also forms part of the Thick-coal; and the sample, like No. 134, came from the neighbourhood of an igneous dyke. Coke slightly coherent, moderately lustrous. Flame yellow, smoky. Colour of the ash, buff.

136. From West Virginia. Coke firm and coherent. Flame yellow, smoky. Colour of the ash, buff.

137. From Pomeroy, on the Ohio river.

138. From Frostburgh, Maryland.

TABLE OF JAPANESE COALS.*

| Locality. | | Number. | Percentage of Ash. | Percentage of Sulphur. | Percentage of Moisture. | Heating power, determined by Thompson's Calorimeter. | Percentage of Coke. | Character of the Coke. |
|-------------|--------------------------|---------|--------------------|------------------------|-------------------------|--|---------------------|--------------------------------|
| Province. | Place. | | | | | | | |
| Hizen ... | Takasima..... | 1 | 4.00 | 1.08 | 1.02 | 15.1 | 57.5 | Bright, hard, and perfect. |
| | Iwanosaki, Co. Amakusa | 2 | 7.50 | 3.26 | .. | 13.2 | .. | A non-caking coal. |
| | Itoyama, do. | 3 | 5.20 | 2.94 | .. | 13.5 | .. | Do. |
| | Nagasaki, do. | 4 | 6.20 | 2.20 | .. | 13.2 | .. | Do. |
| | Gessushima, do. | 5 | 8.10 | 3.38 | .. | 13.0 | .. | Do. |
| | Do. do. | 6 | 8.80 | 5.60 | .. | 12.1 | .. | Do. |
| | Himenokawashi, do. | 7 | 6.00 | 0.92 | .. | 13.5 | .. | Do. |
| | Kishiyama, Co. Karata... | 8 | 5.00 | 4.47 | .. | 14.1 | 56.5 | Bright, hard, and perfect. |
| | Uranotani, do. | 9 | 6.40 | 1.07 | .. | 14.0 | 53.7 | Dull, but hard and compact. |
| | Funakitan, do. | 10 | 5.00 | 0.87 | .. | 13.2 | 54.5 | Do. |
| | Shointani, do. | 11 | 31.00 | 2.35 | .. | 10.5 | 42.3 | Imperfect, very friable. |
| | Sakakuchi, do. | 12 | 5.60 | 1.38 | .. | 13.2 | 52.5 | Dull, but hard and perfect. |
| | Koyaki..... | 13 | 6.20 | 1.03 | .. | 14.6 | 54.0 | Bright, but light and friable. |
| Iwaki | Namesi..... | 14 | 5.80 | 0.95 | .. | 13.2 | .. | A non-caking coal. |
| | Matsu..... | 15 | 11.00 | 3.26 | 2.08 | 13.2 | 52.7 | Bright, hard, and perfect. |
| | Iwaki..... | 16 | 10.70 | 1.82 | 15.00 | 12.1 | 46.2 | Very friable and imperfect. |
| Tsushima. | Tsushima..... | 17 | 14.30 | 4.10 | 1.35 | 11.0 | .. | A non-caking coal. |
| | Kosuda..... | 18 | 8.20 | 0.66 | .. | 8.8 | 27.0 | Do. |
| Hitachi .. | Shiramitsu..... | 19 | 7.00 | 1.46 | .. | 11.4 | 51.0 | Do. |
| | Do. | 20 | 20.90 | 3.03 | .. | 10.7 | 52.2 | Do. |
| Iwaki ... { | Ikuyama, Co. Miike.... | 21 | 7.80 | 4.51 | .. | 15.4 | 55.2 | Bright, but soft and friable. |
| Chikugo .. | Kayakusa..... | 22 | 8.00 | 1.08 | .. | 13.0 | 54.0 | Hard and perfect. |
| Ugo { | Do. | 23 | 8.00 | 0.69 | .. | 13.0 | 54.0 | Do. |
| | Koyamura..... | 24 | 7.20 | 0.67 | .. | 12.4 | 54.0 | Dull, light, and friable. |
| Rikuchu.. | Okawamemura..... | 25 | 8.00 | 1.14 | .. | 13.7 | .. | Dull and imperfect. |

I am indebted to Mr. G. H. Godfrey for the preceding table of Japanese coals, which has been compiled from results obtained in the laboratory of the Imperial Government Mining Office of Japan. Mr. Godfrey states that all the Japanese coals hitherto discovered are of rather recent origin; the Oolitic being the oldest formation in which coal has been found in that country. No. 1, in the table, is reported to be a "best steam coal," and Nos. 8, 9, 10, 13, and 24, "good steam coals." The results obtained with Thompson's calorimeter are in some cases so high, in comparison with the percentage of coke and supposed age of the coals, as to lead to the belief in the possibility of some undetected source of error.

CHINESE COAL AND IRONSTONE.*

Mr. James Henderson, who has recently returned to this country after a residence of about thirty years in China, has favoured me with the following information regarding the Chinese coal-fields, and

* Further information on the subject of Japanese coal will be found at p. 345 *antea*.

* Further information on the subject of Chinese coal will be found at p. 346 *antea*.

the deposits of rich ironstone, which are found in neighbouring localities to the coal:—

“The minerals of the north of China are found in rich deposits in numerous places between the limits of 110° to 130° E. long., and of 34° to 42° N. lat. Ironstone and coal are found in the province of Manchuria; nearly all over the north and west portions of the province of Chihli; and in the provinces of Shan-si, of Honan, and of Shan-tung. The ironstone of Manchuria, so far as yet met with by foreigners, is the black magnetic-iron-ore. Some samples of it, according to analyses made by M. Belliquin at Peking, contain as much as 70 per cent. of metallic iron. Much of the coal of this region is excellent, and well adapted for the use of steamers, and at the port of New-Chwang meets with a ready sale.

“The coal of the north of Chihli is mostly bituminous, and of fair quality: that found amongst the mountains is superior to that found nearer the coast. Ironstone is also said to be found here in several places, but its nature does not seem to be well known to Europeans as yet. The coal in the west of Chihli is the best in the province: that found near Chai-tang in the mountains, about forty miles west of Peking, is quite equal in quality to the best coal of Cardiff. In this locality is also found ironstone—brown hæmatite—extending, by native account, for 40 li or 13 miles. A sample of ironstone from this district was assayed in the Metallurgical Laboratory of the Royal School of Mines, and found to contain about 48·5 per cent. of metallic iron. It is here found in an immense mass on the top of the mountain, some 600 feet above the level of the valley, and nearly 3000 feet above sea-level. So far as it was uncovered, it was one solid mass of ironstone; in the same mountain coal-mines were open and at work. This mountain also contains a sort of blue lime or cement (i.e. a kind of marl), and other valuable products. In this locality is also found anthracitic steam coal of the best quality, as mentioned by Pumpelly, who thoroughly surveyed these Chai-tang coal-mines: two seams here are 40 ft. in thickness, with only a few feet of rock between them. To the east and south of this fine basin of anthracite coal, steam-coal, and ironstone, vast beds of tender anthracite are found, at Muntakow and Fangshan, in the mountains on the edge of the plain. In the north-west, on the plateau extending to Mongolia, are beds of fine bituminous coal and ironstone. In the south of Chihli, and, adjoining it, in the north of the province of Honan, are large fields of bituminous coal and fine brown hæmatite. Two samples of this hæmatite found at P'ung O'hung and analysed in Peking, were found to contain about 50 per cent. of metallic iron; and the mean of eleven samples of the same ores, analysed by Mr. R. Smith at the Royal School of Mines, gave 53·33 per cent. of metallic iron. The ironstone is here found in the mountains in large masses, in limestone, and it is also found scattered in small pieces all over the face of the mountains. The coal-fields—containing principally bituminous coal—surround the ironstone on all sides, and in some of the pits seams of 8 to 10 feet thick are found. Coal in many places is also found within a few feet of

the surface. The coal-fields here also contain numerous bands of brown clay-ironstone, some seams of it being visible within six feet of the surface; in addition, the coal-fields contain an inexhaustible supply of potter's clay, advantage of which is taken in the numerous and extensive potteries at P'ung C'hung.¹

"To the west of Chihli lies the large and elevated province of Shan-si, rich in minerals of all descriptions. The following quotation from a recent work by the Rev. Alexander Williamson, entitled 'Journeys in North China, Manchuria, and Eastern Mongolia; with some Account of Corea,' will in part show the extent of the district:— 'The mineral resources of Shan-si are great and varied. Coal literally abounds in all quarters, although there are several places more famous than others. The first coal district may be said to commence at Ta-tung-foo on the north, and reaches to the neighbourhood of Tai-yuen-foo. A second comprises the valley of the Ching-shing-ho, embracing the coal-fields of Ping-ding-chow and Yu-hien. A third lies in long. 110° 45' E., and between lat. 36° 50' and 37° 30' N. Another coal district lies towards the west in the neighbourhood of Tai-ping-hien, lat. 35° 52' N. A fifth lies on the N.W. of Shan-si, not far from the Yellow River. And, lastly, there is a most important coal-producing district on the S.E., in the neighbourhood of Loo-ngan-foo. Thus coal is found, here and there, all over Shan-si, whose area is 55,268 square miles.' (P. 152.)

"To sum up:—Throughout Shan-si we found several kinds of coal, bituminous, anthracite, and lignite. One variety particularly attracted our attention, as it was quite new to us; it was of a clear shining black colour, light, easily igniting, but emitting no smoke, and leaving no ashes.² It is not coke, but a natural product which the natives called coal-charcoal.' (P. 154.)

"Not only have we coal in Shan-si, but abundance of iron; a fact apparently quite unknown to Europe. This mineral is found in many places throughout the province, but there are four districts especially famed for it. The first is the district of Ping-ding-chow, referred to above as producing coal, in which are the cities of Yu-hien, lat. 30° 12' N., long. 113° 15' E., and Lo-ping, lat. 37° 39' N., long. 113° 40' E., where iron-ore mines abound. The next district is the neighbourhood of Tai-yuen-foo and Yu-tze-hien. Here, outside the east gate and at the hills thirteen miles to the north-west, are iron manufactories. Towards the south-west of the province, in the district of Tai-ping-hien, lat. 35° 52', are great quantities of iron; also in Kuih-yu-hien and Yo-yang-hien. But the most famed district is that of Loo-ngan-foo, lat. 36° 7' N. The mines here produce the iron of which the Chinese make their razors, knives, and cutlery. . . . Besides these districts and others mentioned in Chinese books, I am persuaded that iron exists in many quarters not yet known to the Chinese, or, if known, not

¹ The accents in the name P'ung C'hung are intended to show that the second letter of each word is aspirated.

² It must be understood that the author is not to be held responsible for the correctness of this statement.

deemed by them worth working, owing to the abundance and cheapness of that already in the market.' (Pp. 156, 157.)

"A sample of ironstone from Ping-ding-chow, in Shan-si, was assayed in the Metallurgical Laboratory of the Royal School of Mines. It was brown hæmatite, and contained about 48·5 per cent. of metallic iron. The ironstone of Ping-ding-chow was found about thirty feet below the surface of the ground. At other places, such as Yang-ching, in the south of the province of Shan-si, the ironstone and coal are both found in the same mountain range, as is the case at Chai-tang, in the west of Chihli.

"The province of Shan-tung, in the east of Chihli, also contains a very large and varied assortment of minerals. In Mr. Williamson's book above mentioned, will be found nearly all the information about the minerals in that province that foreigners have at present.

"The province of Honan is also rich in minerals of various kinds.

"Comparatively little is really known of the extent of the coal and ironstone fields of China, so that one cannot speak with any degree of confidence upon the subject.

"There is not at the present day a single coal-mine in China worked on scientific principles; there is neither a steam-engine nor pump at any one mine. There is not a single blast-furnace for smelting ironstone in the whole country. At the present time the iron ore is broken up into small pieces, mixed with anthracite coal, and put into small clay crucibles; 60 or 120 of them being fired at one time by means of hand-bellows. When the ore is considered smelted the crucible is broken, and the contents, in the shape of a small cap of cast-iron, is taken out; this is the general plan of operation, but the ore is also sometimes smelted in large pits, the yield of the pit being about 5 *piculs*, or 6 cwt.; in this state it is far from pure, and is sold at the works at 5 *cash* per *catty*, equal to 1s. 6d. per cwt., or 30s. per ton.

"The high price the Chinese have been called upon to pay of late for foreign-made pig-iron—sometimes as high as £10 per ton, and for foreign coal a proportionally high rate—has induced the authorities to commence the working of their deposits of coal and ironstone on scientific principles, and the first field chosen for their operations is at P'ung C'hung, near Tze-chow, in the county of Ta-ming-fu, in the southern corner of the province of Chihli, and bordering on that of Honan.

"It would have been impossible to have selected any place richer in coal, ironstone, and limestone than P'ung C'hung; and from its position on the borders of the great plain of Chihli, on a plateau some 300 feet above the level of the plain, it is easy of access. It is intended, by means of a tramway, to carry the produce of the mines down to one of the small rivers, of which there are several about twenty-five miles distant from the mines, and thence by water to Tientsin, for the supply, in the first place, of the government arsenals and shipping.

"The coal and ironstone fields of China, especially the latter,

are so little known, that the people of the province, all along the high road from Peking to P'ung C'hung—a ten-days' journey by cart—asserted that there was no ironstone in the province of Chihli; and even the inhabitants of P'ung C'hung itself, living within two miles of the mountain containing the ironstone, asserted like the others that there was no ironstone in the province. Coal-mining and the manufacture of earthenware, in numerous and extensive potteries, is carried on to a great extent here; we may therefore believe that had the natives of the place known of the ironstone and its great value, it would also have been worked by them. Although the ironstone was unknown to the natives of the present day, yet in ancient Chinese records—some 2000 years old—this very place, where the Chinese authorities are now about to commence the working of ironstone, is mentioned as being the spot where the loadstone was first discovered in China: this statement is made on the authority of the Rev. Joseph Edkins, of the London Missionary Society at Peking, who has taken great interest in the mineral resources of China.

“To His Excellency Li-hung-chang, Viceroy of the province of Chihli, and one of the most enlightened of the natives of China, belongs the honour of conceiving the project of working the coal and ironstone of China on modern principles, and of giving orders for its immediate execution. There can be no doubt but that his example will be speedily followed by several of the other Viceroys and Governors of provinces in China. And before long we shall most likely be able to speak with more confidence than we can do at present, of the extent of the coal and ironstone fields of China.”

It is stated, on p. 346 *antea*, that “the only Chinese mines which can be said to be worked in a business-like manner are those in the island of Formosa.” Since the article, in which this passage occurs, was sent to press, I have been informed, on trustworthy authority, that even the mines of Formosa cannot be said to be worked “in a business-like manner;” and that the statement in question is therefore incorrect.

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ADDENDUM TO PP. 532-535.

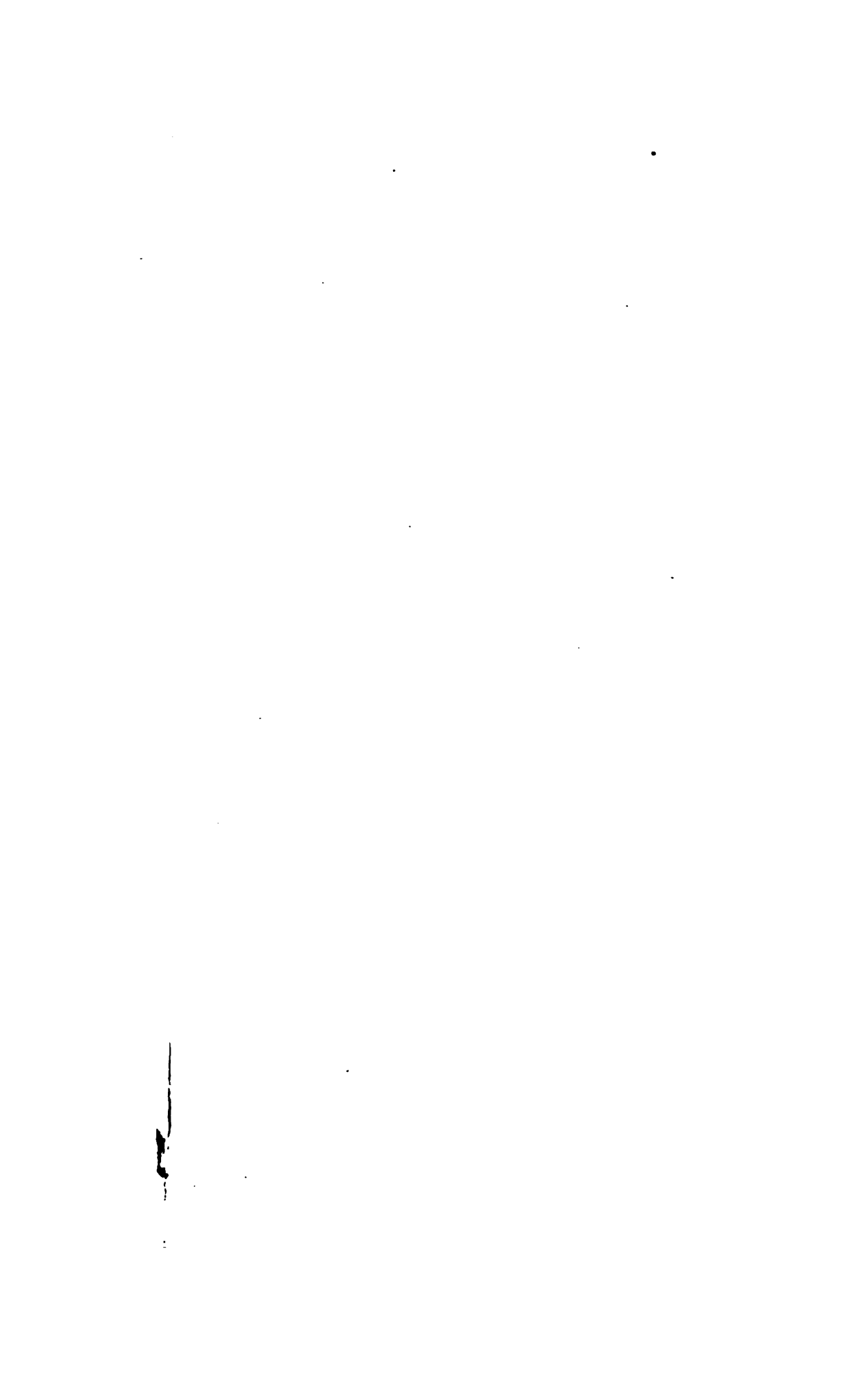
IN the historical notice of the introduction of methods for utilising the waste heat of furnaces (pp. 532-535 *antea*), I omitted, by an oversight, to mention the name of a remarkable man, the Rev. Robert Stirling, of the Church of Scotland, in connection with the development of the regenerative principle. Mr. Stirling obtained a patent in Scotland in 1816, which was cited at the great trial in 1843, of Neilson *v.* Baird and Company, in proof of the want of novelty in Neilson's patented invention of the hot-blast. In my volume on Iron and Steel, published in 1864, I stated in the article on hot-blast (pp. 394 *et seq.*) that I had been unable to obtain sight of Stirling's specification; and it was not until 1873 that I had the opportunity of reading it, thanks to my friend Mr. Lewis Gordon, formerly Professor of Engineering at the University of Glasgow, who kindly presented me with a literal copy of it. The patent was signed and sealed January 20, 1817. The following extracts from the specification will show that Stirling had a clear conception of the regenerative principle, and of the value of its application, both in increasing temperature and in lessening the waste of fuel in furnaces.

"All my improvements for diminishing the consumption of fuel consist of the different forms or modifications of a new method, contrivance, or mechanical arrangements for heating and cooling liquids, airs, or gases, and other bodies, by the use of which contrivance heat is abstracted from one portion of such liquids, airs, and other bodies, and communicated to another portion with very little loss. So that in all cases where a constant succession of heated liquids or other bodies is required, the quantity of fuel necessary to maintain or supply it, is by this contrivance greatly diminished." After having described the construction of certain apparatus suitable for particular applications of the regenerative principle, Stirling adds: "But the benefit to be derived from this contrivance, arises from the fluids and other bodies to be heated, and those to be cooled, *being made to move in opposite directions* [the italics are mine]; and it is for the invention or improvement of this arrangement that I have obtained His Majesty's letters patent." He describes how the principle in question may be applied to glass-melting furnaces, or others, asserting that by such application "much more intense heat" can be produced, with less consumption of fuel than in ordinary furnaces. His description is accompanied by sketches, which, though rough and imperfect, yet give an intelligible notion of the arrangement. In the middle of a long rectangular solid mass of refractory brick or stonework is shown a fire-place in section, from each side of which proceeds horizontally a long, narrow, arched flue, so that there are two similar flues, one towards the left and the other towards the right; both are open at their ends, which may be indicated by the letters *A* and *B*, respectively. Above the fire-place an opening is indicated for introducing the fuel, which opening is capable of being tightly closed. At a short distance from each side of the fire-place there is a cavity for the reception of the substance to be heated, over which cavities the flame passes directly in its course to the flues, first over one cavity, say to the left, and then over the other to the right, the direction of the flame being made to change at intervals. "The air which supports combustion is alternately introduced at *A* and *B* by blowing-engines, bellows, or any

other means, and the gases and vapours which arise from the fire pass off in an opposite direction, leaving the greater part of their heat in the flues. This heat is taken up by the air which supports the fire, and is again left in the opposite flue, along with the additional quantity produced by combustion. In this manner the heat is accumulated in the furnace and the part of the flues adjacent to it. The bodies to be heated are placed [in the cavities above mentioned], and the openings by which they are introduced are accurately closed. The furnaces and flues are constructed of the best fire-bricks, or any material that may better resist the intense heat; and the mason-work is made sufficiently thick to prevent the waste of heat, as in other furnaces. The form and management of the furnace and flues may be varied according to circumstances; but it must be remembered that the narrower or longer the flues are, and the more frequently the direction of the air is changed, the greater the saving of fuel and the intensity of the heat produced."

From the foregoing account it will, I think, be evident that, supposing no prior record of a similar invention to exist—and, so far as I know, there is no such record—Stirling may be regarded as the father of the regenerative principle. In the copy of Stirling's specification in my possession, Mr. Gordon has inserted a marginal note in reference to the preceding description, "Siemens's Regenerator described," and Mr. Gordon, it may be added, is the brother-in-law of Mr. C. W. Siemens.

Stirling is, perhaps, best known through his caloric engine, which is described in the specification above quoted.

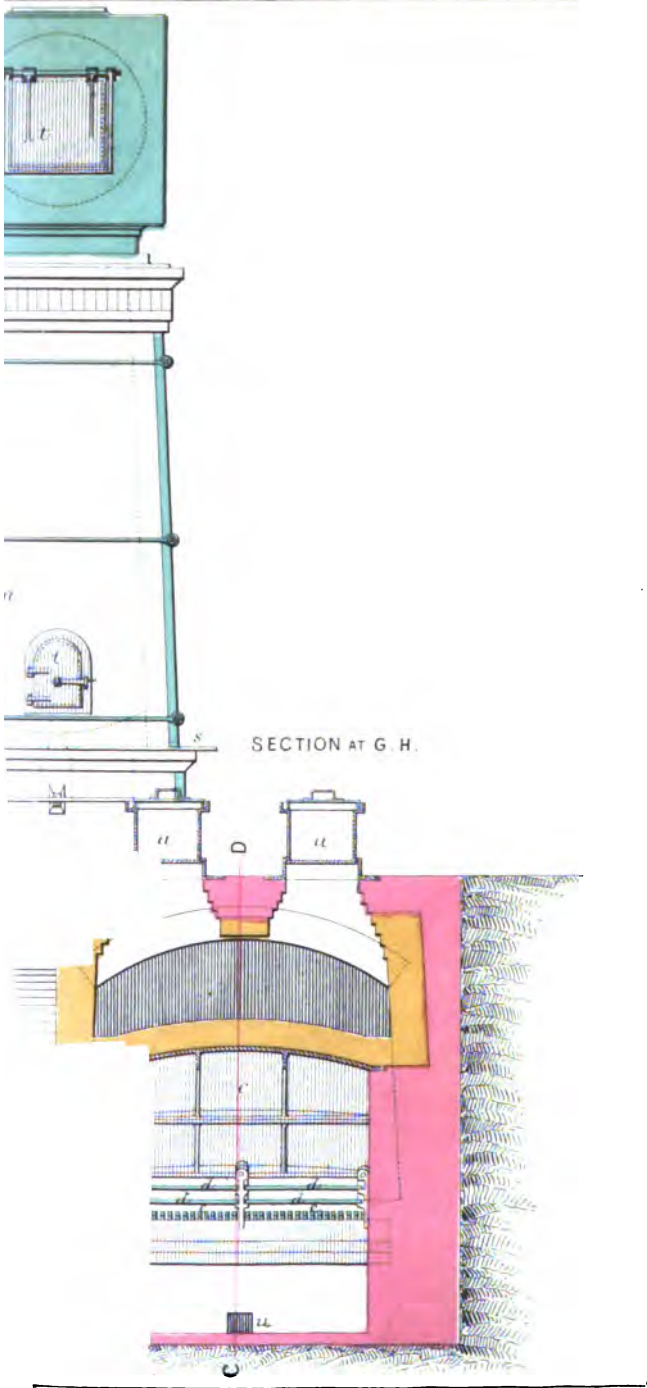


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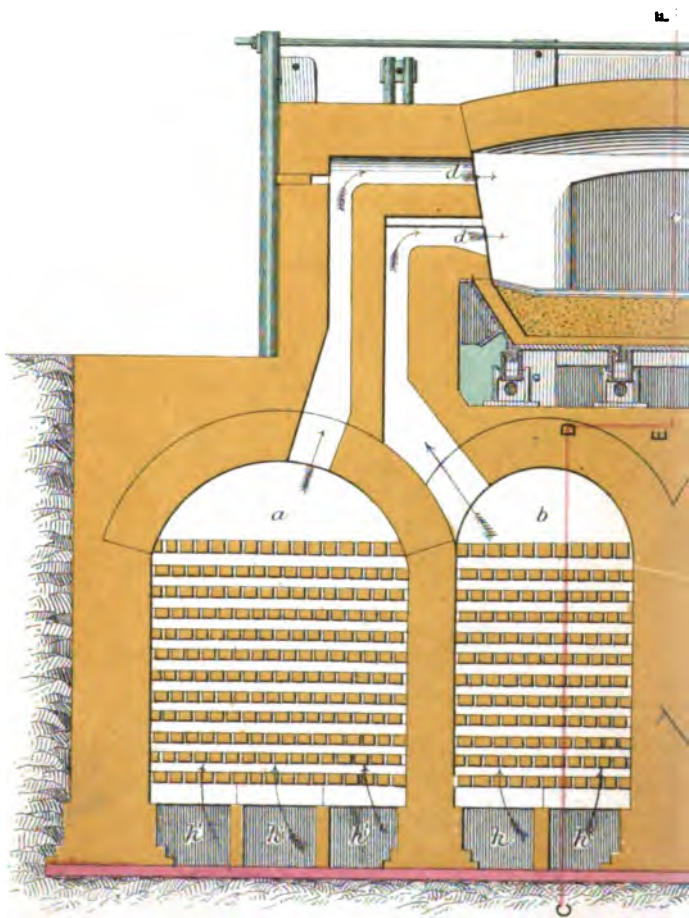
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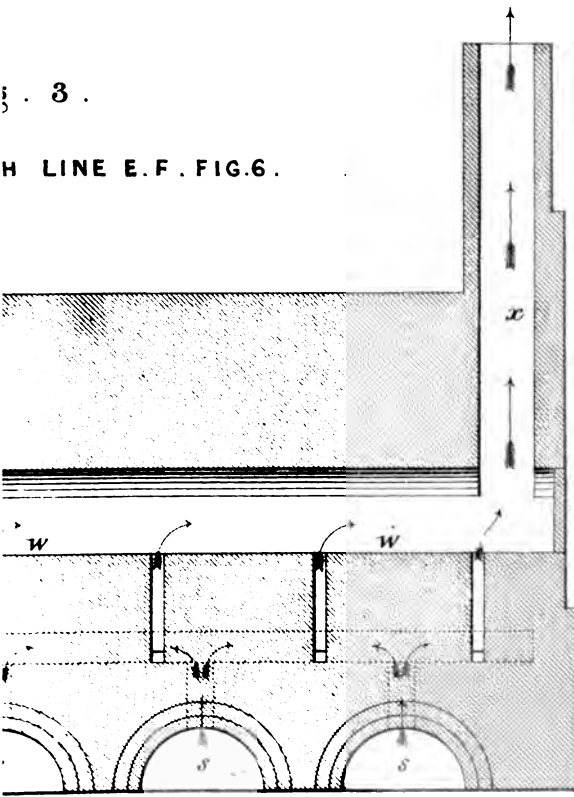


SECTION



§ . 3 .

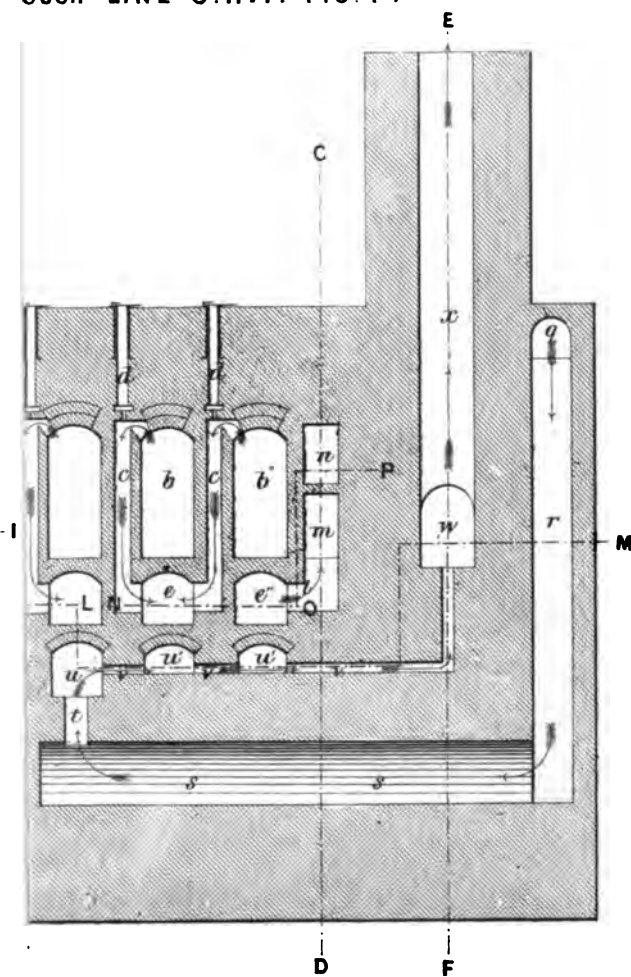
H LINE E.F. FIG.6.



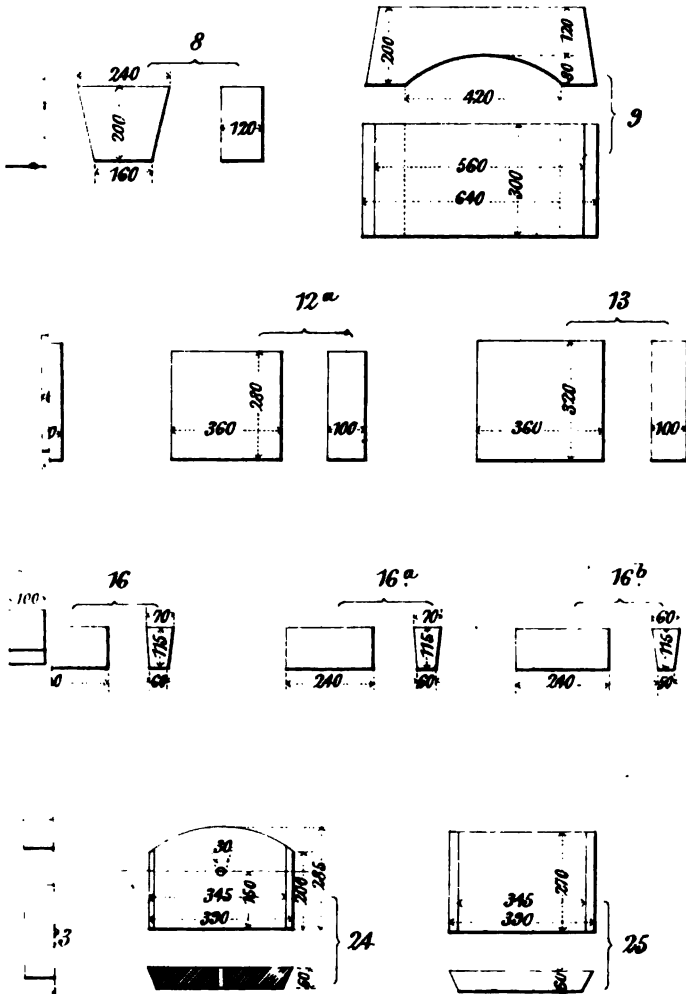
OKE-OVEN.

§ . 6 .

OUGH LINE G.H.I. FIG.4.

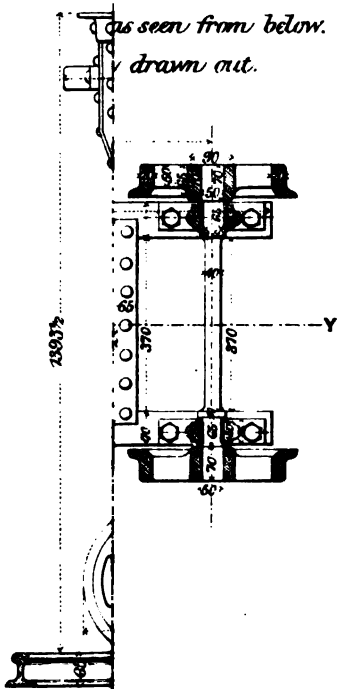


CV



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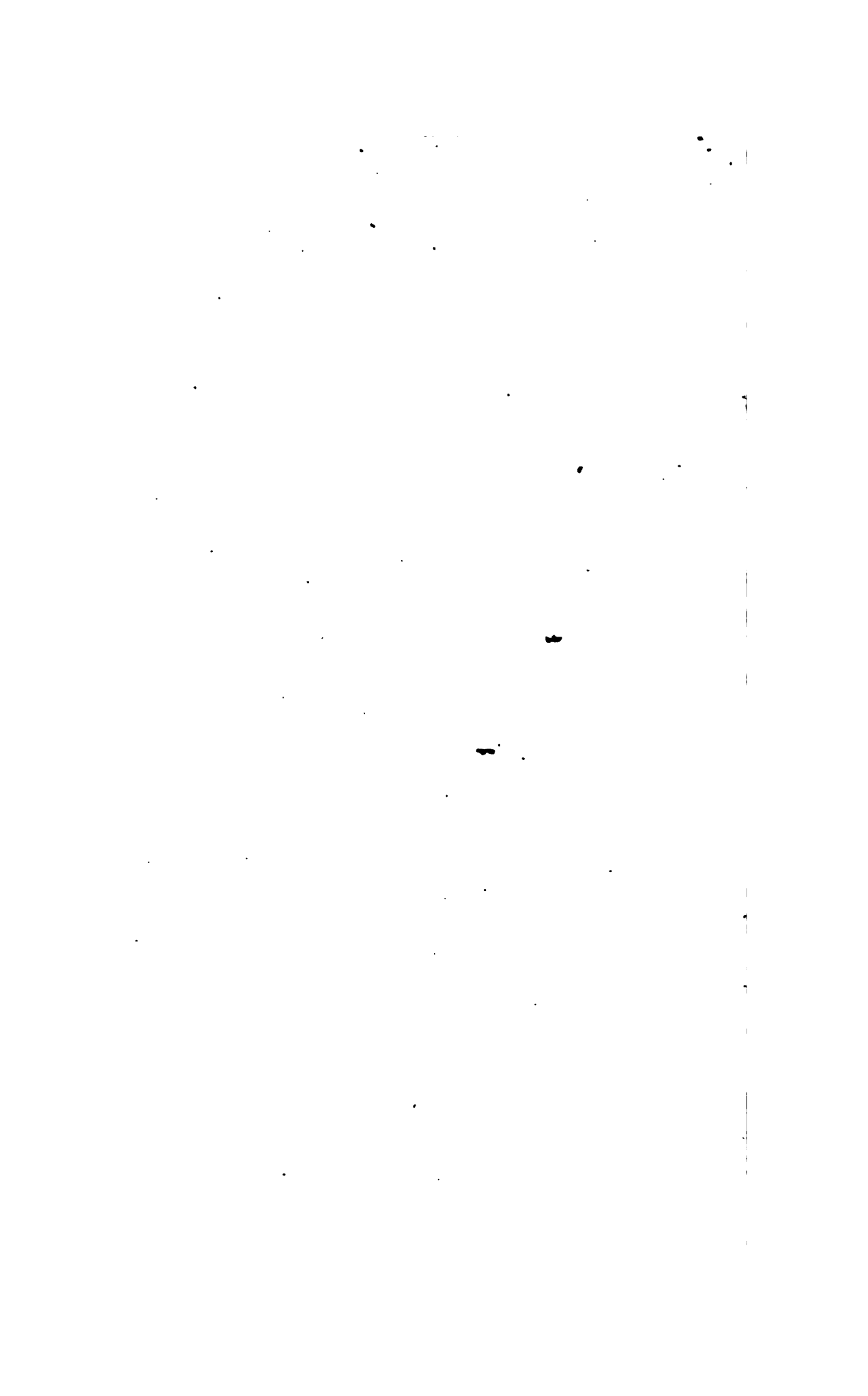
VEN. — TRAMS



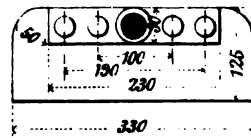
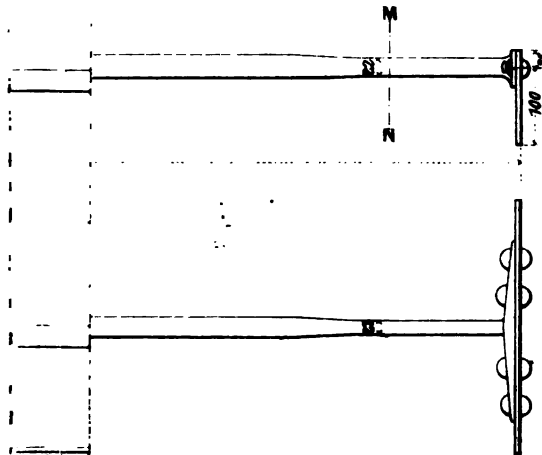
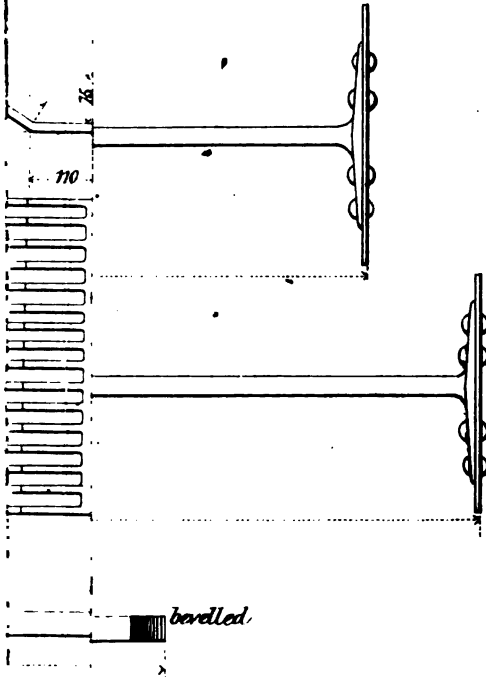
English. Feet.

Given in Millimetres.

French Measures.



P.E.E.S



Section through M.N.

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PLATE 8

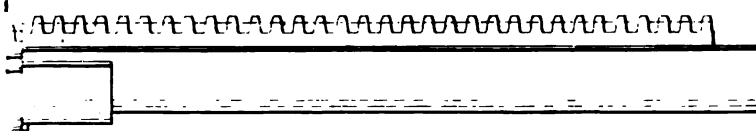
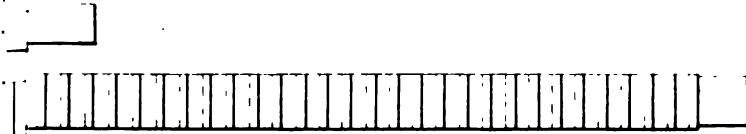


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